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A workable theory of instruction appears to depend upon the development of measurement instruments, which operationally define concepts such as transfer, analysis, synthesis, and evaluation, to make possible empirical investigation of the relationships of methods of instruction and learner variables to the attainment of different types of educational objectives. This project developed 31-item sets in the physical sciences, and administered them to secondary school students. The sets of items followed generally the levels of understanding postulated in Bloom's Taxonomy of Education Objectives. The reproducibility coefficients were determined for each item set (.75 to .95). It was generally found that the difficulty of the "comprehension," "extrapolation," and "application" items was highly related to the nature of the principle involved. At the lower levels, item sets were typically very easy, while "analysis" items were often too difficult for the majority of students. Item sets as constructed appear to be useful as research tools, but not for evaluation of instruction as it exists today. It is probably possible to construct other cumulative and hierarchical taxonomies of educational objectives in which the items increase in difficulty with each level and are highly reproducible and scalable. Sample item sets are appended. (Author/CJ)

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January 1969

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Development of Scalable Test Items to Measure Thinking Levels of Secondary School Students

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Richard B. Smith

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The research reported herein was performed pursuant to a contract with the Office of Education, U. S. Department of Health, Education and Welfare. Contractor undertaking such projects under Government sponsorship are encouraged to express freely their professional judgement in the conduct of the project. Points of view or opinions stated do not, therefore, necessarily represent official Office of Education position or Policy.

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TABLE OF CONTENTS

Page

INTRODUCTION 1

- A. The Importance of Structure 1
- B. Rationale for the Study 5
- C. General Objectives of the Project 6
- D. Related Research 6

METHOD 10

- A. Description of Activities 10
- B. A Sample Set of Items 11

RESULTS 17

DISCUSSION 18

CONCLUSIONS, IMPLICATIONS, (and RECOMMENDATIONS) 21

- A. Conclusions 21
- B. Implications 21
- C. Recommendations 22

SUMMARY 24

REFERENCES 26

APPENDIX A

INTRODUCTION

The Importance of Structure

A current trend in education is to examine the basic structure of the subject matter areas with an eye toward improving the understanding, retention, and applicability of the content and principles taught. This has been the general approach of the Biological Sciences Curriculum Study group, the American Association for the Advancement of Science group in the Elementary Science Curriculum Study, MIT's Physical Science Study group, and the Social Science Education Consortium.

These groups are representative of the many different groups looking at the structure of the various content areas. To these can be added all of the various groups working on the new mathematics, devising different approaches to the teaching of foreign languages, and studying revisions in the English curriculum. It seems that every content area is being reviewed in an attempt to develop a structure which will result in students being able to perform the higher cognitive processes.

Bruner[2], in reporting on the Woods Hole Conference of the National Academy of Science, postulated four basic claims that have been made for teaching the fundamental structure of a subject claims which he says are in need of detailed study. These are as follows:

1) That understanding fundamentals makes a subject more comprehensible.

2) That the most basic thing that can be said about human memory. . . , is that unless detail is placed into a structural pattern, it is rapidly forgotten.

3) That, an understanding of fundamental principles and ideas, . . . , appears to be the main road to adequate "transfer of training."

4) That by constantly reexaming material taught in elementary and secondary schools for its fundamental character, one is able to narrow the gap between "advanced" knowledge and "elementary" knowledge.

The Measurement of Structure

We have had in the past a great deal of repetitions and conflicting evidence as to the effectiveness of various instructional techniques (example vs. non-example; discovery vs. verbalization; the effectiveness of various types of media; the effects of learning set; autocratic vs. democratic classroom procedures; lecture vs. discussion; rule-example vs. example-rule, etc.). It is the contention of the writer that a great deal of the inconsistency of the findings can be attributed to the kind of measurement performed in attempting to assess the results of the experimental treatments. In most cases the instruments used are not reported with the findings, and no information is given regarding the nature of the items used. It is impossible to tell whether the items utilized measured anything other than the "knowledge" level mentioned in the Taxonomy of Educational Objectives: Cognitive Domain.[1] "Knowledge" according to the Taxonomy authors is considered to be recall or recognition without understanding. Added weight can perhaps be lent this position by the findings of the Taxonomy authors who state:

> We have also attempted to organize some of the literature on the growth, retention, and transfer of the different types of educational outcomes or behaviors. Here we find very little relevant research. For the most part, research on problems in retention, growth, and transfer has not been very specific with respect to the particular behavior involved. Thus, we are usually not able to determine from this research whether one kind of behavior is retained for a longer period of time than another or which kinds of educative experiences are most efficient in producing a particular kind of behavior. Many claims have been made for different educational procedures, particularly in relation to permanence of learning; but seldom have these been buttressed by research findings.

The authors of the Taxonomy of Educational Objectives have attempted to arrange the ordering of the classes of educational behaviors from simple to complex. The simple to complex ordering of the classes of the Taxonomy is based upon the notion that a series of simple behaviors combines to form more complex behaviors. The ordering implies that one must have "knowledge" before one can "comprehend"; that one must be able to "comprehend" before one can "apply"; that the "analysis" of a communication is more difficult than the "comprehension" or "application" of the rules or principles involved in the communication; that the "synthesis" of a communication requires a higher degree of understanding than does the "analysis" of the "communication"; and finally, that "evaluation" of the communication in terms of internal or external evidences is the most complicated mental process.

Brief definitions of the major categories of the Taxonomy follow:

Knowledge. Knowledge, as defined here, involves the recall of methods and processes, or the recall of a pattern, structure, or setting. For measurement purposes, the recall situation involves little more than bringing to mind the appropriate material. Although some alteration of the material may be required, this is a relatively minor part of the task. The knowledge objectives emphasize most the psychological processes of remembering.

Comprehension. This represents the lowest level of understanding. It refers to a type of understanding or apprehension such that the individual knows what is being communicated without necessarily relating it to the other material or seeing its fullest implications.

Application. Application involves the use of abstractions in particular and concrete situations. The abstractions may be in the form of general ideas, rules of procedures, or generalized methods. The abstractions may also be technical principles, ideas, and theories which must be remembered and applied.

Analysis. The breakdown of a communication into its constituent elements or parts such that the relative hierarchy of ideas is made clear and/or the relations between the ideas expressed are made explicit. Such analyses are intended to clarify the communication, to indicate how the communication is organized, and the way in which it manages to convey its effects, as well as its basis and arrangement.

Synthesis. Synthesis is the putting together of elements and parts so as to form a whole. This involves the process of working with pieces, parts, elements, etc., and arranging and combining them in such a way as to constitute a pattern or structure not clearly there before.

Evaluation. Evaluation involves judgments about the value of material and methods for given purposes, quantitive and qualitative judgments about the extent to which material and methods satisfy criteria, and the use of a standard of appraisal. The criteria may be those determined by the student or those which are given to him.

Evidence is mounting that the cognitive process suggested by the Taxonomy are hierarchial and cumulative (Smith[11]; Cox[3]; Furst[5]; Dressel[4]) at least through the application level.

It is the contention of most authorities in the field that teachers should utilize a hypothesis testing approach to education. Tyler,[13] Travers,[12] McDonald,[9] and Bloom,[1] to name a few, have suggested that the educational act should consist of (1) specifying the specific desired student behaviors, (2) designing learning experiences to achieve these behaviors and (3) evaluating to determine the extent to which these behaviors have been achieved. The hypothesis regarding the effectiveness of instruction is then either accepted or rejected.

The Taxonomy of Educational Objectives: Cognitive Domain is intended to provide a classification for the goals of our educational systems. It was designed to help teachers and administrators deal with curricular problems by providing a model for the analysis of such cognitive educational outcomes as remembering, thinking, and problem solving.

Measurement in our schools is at the present time largely limited to the lowest Taxonomy category of "knowledge." According to the Taxonomy, the "knowledge" category is not considered a form of understanding.

It is likely that in our schools, where the importance of any objective seems to be determined largely by our ability to measure it, grade conscious students memorize and give us back exactly what we measure: "knowledge" without understanding. The effectiveness of the Taxonomy for measuring the higher mental process involved.

In view of the evidence supporting the existence of a hierarchial and cumulative continuum of cognitive processes we should re-examine our position on the measurement of student achievement in the schools. The entire concept of content validity should be re-examined in the light of the scalability of the cognitive process.

The cognitive levels suggested by the Taxonomy of Educational Objectives indicate that the teacher should be concerned not only with the content validity of his test, but should also be concerned with the level of understanding measured by the test. The cumulative and hierarchial structuring of cognitive processes suggest that the teacher should, in fact, be concerned with how far the learner is along the way toward being able to achieve the "application," " analysi," "synthesis," or evaluation," levels. The instructional procedure used for the student who is at the "knowledge" level is probably quite different from the instructional procedure that is effective in getting the student, who comprehends a principle, to position where he can apply it in different situations. The instructional task involved in moving the student from the ability to apply a principle to a position where he can analyze a theory or structure in terms of internal and external evidences imply greatly different instructional techniques.

The cumulative and hierarchial structuring of the cognitive processes further suggests that we should develop cumulative and hierarchial sets of items that lead up to and measure the behavioral objective at the level specified. The sets of items should follow the logical structuring of the subject matter, and build to the cognitive levels specified by the educational objectives. Thus, if we are going to develop courses that attempt to build a logical theory or structure, we should construct sets of test items that will measure the important steps along the way to analysis and evaluation of the structure.

Rationale for the Study

Cumulative and hierarchial sets of items are badly needed in all subject matter areas. The item sets must be developed so that we can:

1. Diagnose more accurately a student's learning difficulties to determine how far he has come toward achieving the specified criterion level stated in the educational objectives.

2. Determine how effective various teaching methods are for bringing a student to higher levels of understanding.

3. Investigate the relationship of intelligence to the various cognitive levels of achievement.

4. Investigate the relationship of retention to the level of taxonomic achievement acquired by the student.

5. Investigate the part played by reading in achieving a high score on the sets of items - particularly the higher level items of analysis and evaluation.

6. Determine whether or not the higher levels of the Taxonomy (analysis and evaluation) are truly different cognitive processes from those used in "comprehension" and "application," and look into the problem of teaching for the cognitive processes of "analysis" and "evaluation."

7. Relate motivation to the level of understanding achieved.

8. Gather more evidence regarding the age and grade levels at which the various cognitive functions can be performed.

9. Examine the characteristics of learners as they relate to the level of understanding achieved.

General Objectives of the Project

This project is of importance to curriculum improvement at all grade levels. It would seem that the instruments suggested in the project would be of importance in helping to determine what can be taught at the various grade levels as well as giving us information regarding the degree of understanding that we can logically expect to obtain. The measurement devices should also be of some use in helping teachers evaluate the effectiveness of different instructional techniques for attaining the various *Taxonomy* levels of understanding. The scalable test items can also be used to provide information regarding functions at any given grade level.

Research Related to a Taxonomic Measurement of Cognitive Structure and Samples of Materials Previously Developed

Research work concerned with the measurement of levels of understanding has largely developed using Bloom's *Taxonomy of Educational Objectives: Cognitive Domain* as a theory base. The experimental approaches utilized in attempting to validate the *Taxonomy* have generally followed two patterns. The first group of experimenters generally attempted to validate the *Taxonomy's* structure by the process of classifying already constructed items. The experimenters then looked at the average difficulty level of the items in each major *Taxonomy* class. The rationale followed considered that if any category includes the processes of all lower-order categories, plus a unique component, then the mean score should decrease as the level of category increases. This inverse relationship between level of the *Taxonomy* category and difficulty level has held up consistently.

This group of experimenters has also looked at item and sub-test intercorrelations in an attempt to determine the degree to which these correlations formed a Guttman simplex. If the simplicial structure is satisfied, the correlation matrix will be such that the largest values will be along the upper-left, lower-right diagonal, followed by the next larger values in the adjacent diagonals and the smallest values in the upper-right and lower-left corners of the matrix. This approach has not been satisfactory because of the way differences in item difficulty level effect phi coefficients. This problem is central to the theme of Kropp, Stoker and Baslow's article,[8] "The Validation of the *Taxonomy of Educational Objectives*." A similar finding had also been reported earlier by Guttman[7].

A second group of researchers interested in the scalability of the cognitive processes suggested by the Taxonomy, approached the problem by constructing items at the various Taxonomy levels. These items were developed logically out of a particular concept. For example, Smith and Paterson[11] developed a twenty-item multiple-choice test consisting of four items relating to each of five principles. The items did not measure cognitive processes above the sub-class of "extrapolation" in the Taxonomy hierarchy. Five four-option multiple-choice items measuring "knowledge-of-principles" were written (one item for each of five principles related to the teaching-learning situation). The five "knowledge-of-principle" items required only that the student be able to recall a principle--not that he understand it. The principles or relationships measured were:

1) The principle of selective perception
2) The relationship of norms to test interpretation
3) The relationship of environment to intelligence test performance
4) The relationship of set to problem solving
5) The relationship of test-retest reliability to relative placement on the distribution curves

After the completion of the five "knowledge-of-principle" items, five multiple-choice items that required that the students "extrapolate" from a specific principle were constructed. The stem of the "extrapolation" items consisted of a hypothetical situation. The student was then asked to specify what action should be taken in view of his understanding of a particular principle. It was found extremely difficult if not impossible to write multiple-choice items in the behavioral sciences that required the student to respond to a hypothetical situation without specifying which principle or theory in terms of which he was to respond. These items nearly always contained ambiguity stemming from the current state of psychological theory. Thus, it was not possible to write items which fulfilled the Taxonomy's criteria for "application" items.

Five other multiple-choice items were written in an attempt to measure the "interpretation" of basic communications dealing with the meaning of the five principles. The stem of the items included a basic communication designed to convey an understanding of the principle involved. The student was then asked to identify and comprehend the major ideas which were included in the communication as well as to understand their interrelationships.

The final five items were designed to measure "knowledge" of the terminology necessary for "comprehension" and "extrapolation" from the five principles. The items which measure "knowledge of terminology" are characteristic of the typical multiple-choice items used by instructors. The terms measured were those most relevant to the understanding of the principles to be developed.

In order to prevent one item from giving clues to the other items involving the same principle it was necessary to order the items and place them on transparencies. The order in which the items involving a particular principle were presented is as follows:

1) "Extrapolation" from the principle or relationship
2) "Knowledge" of the principle or relationship
3) "Knowledge" of terminology involved in the principle or relationship
4) "Interpretation" of a communication concerned with the understanding of the principle or relationship

The item intercorrelations for each of the five educational psychology concepts at the four Taxonomy levels were adjusted for the differences in difficulty levels of the items by the use of phi-to-phi max. ratios. The phi-to-phi max. ratios were then converted to Z scores and averaged over each of the four Taxonomy classes. The Z scores reported are low and generally positive. They do not confirm a simple-to-complex continuum of the Taxonomy.

The above statistical procedure, while it did tend to take into account differences in difficulty levels, and did raise the correlation coefficients, still suffers greatly from the problem previously mentioned.

Perhaps the most significant finding of this study is the lack of relationship between items dealing with the same principle but requiring different cognitive processes. An examination of the phi-to-phi max. ratio shows a range from .07 to .40 of the total possible phi correlation between "knowledge of the principle" and "extrapolation" from the principle. The .40 phi-to-phi max. ratio is in all probability spuriously high because one of the items was too easy and did not function properly.

The items listed below build logically to "extrapolation" from the principle. The highest phi-to-phi max. ratio found in this group of test items is .39. Note that this group of items does not include the item measuring "comprehension" (i.e., translation or interpretation) of the principle. This is because it was generally found that items written at this level vary with all of the factors that affect reading difficulty and thus, in general do not scale.

1. A "set" is

   a. a facilitating group of behaviors related to a stimulus situation.
   b. an inhibiting group of behaviors related to a stimulus situation.
   c. a non-functional group of behaviors related to a stimulus situation.
   *d. a predisposition to view a problem situation in a given way.

2. Which of the following best explains the relationship of "sets" to the solving of intellectual problems?

   a. A set enables the individual to transfer large bodies of facilitating information to all related problem situations.
   b. Sets pertain to skill learning, but not to problem solving.
   c. Sets are inconsistent with the notion of stimulus-response problem solving.
   *d. Sets narrow perception, and thus may interfere with problem solving.

3. An arithmetic teacher wishes to have her students learn to recognize and solve the following types of problems:

   1. Q is what percent of B?
   2. X percent of A is what number?
   3. B is X percent of what number?

   According to your knowledge concerning the formation of sets, the teacher should:

   a. Have the individuals work until they discover the relationship.
   b. Work a series of the first type, and then a series of the second type, followed by a series of the third type of problem.
   *c. Present all types of problems in each exercise.
   d. Spend a week on each separate type of problem, and then repeat this series several times during the year.

The highest correlation between these items was .39 between "knowledge" of term and "knowledge" of principle (the others were considerably lower). However, a Goodenough reproducibility coefficient of .95 was found among the three items when they were administered to 106 educational psychology students. The coefficient of reproducibiltiy, computed in the above manner described, is a measure of the degree of accuracy with which the statement responses can be reproduced from knowlege of the total score alone. The reproducibility coefficient for the other sets of items ranged upward from .84.

Figures such as these reflect the inappropriateness of the product moment correlation for measuring the scalability of the various cognitive processes. Other possible approaches to the problem have been suggested (Guttman,[7] Kropp[8]). However, these procedures are also basically correlational, and while they limit the amount of error, they by no means remove it.

METHOD

Description of Activities

This project is concerned with the development of sets of scalable items in the content areas of physical science. The sets of items in general follow the levels of understanding postulated by the Taxonomy. The items build logically from "knowledge" of key terms to "knowledge" of principle involving the relationship between the key terms; to "comprehension" of the principle and/or generic coding of the relationship; to "extrapolation" from the principle or code to "application" of the principle, code or relationship; to different problem situations, and finally to items which require the individual to be able to analyze communications, experiments or happenings in terms of the internal consistency of the concepts involved, logical consistency of the structure of the theory or communication, and premises or assumptions made.

The proposed project is novel in at least four ways:

1. The items in the project are written so that they build logically upon one another in such a way that each item requires the same information and a little more than the previous item.

2. Each set of items is constructed out of a communication which attempts to develop one principle to the point where the student can evaluate the principle, in terms of its application, internal consistency and available external evidences. The communication contains within it a statement of the meaning of the key concepts which are necessary for the understanding of the

principle to be developed. This statement will be made in as clear and concise terms as is possible. The first item to be constructed will measure the "knowledge of the key term or terms." The second item in the series will require that the student recognize a restatement of the principle stated in the communication (knowledge of principle). The third item is to be constructed so that the student is required to decode and encode the data given, in the the basic communication. The third item will require therefore, more than the restatement of the principle required by item two (knowledge of principle). It will require the student to recognize the principle even when it has been stated much differently. In item four the student is asked to use the code derived from the communication to go beyond the data (extrapolation). This is not expected to involve a new problem situation. In item five (application) the student is asked to use the principle (code) in a different problem situation. Item six (analysis) requires the student to look at the communication and data provided in terms of the premises and relationships. Item seven (evaluation) will involve the evaluation of the communication in terms of internal consistency or external evidences to determine the usefulness of the principle for specific applications.

3. The item sets contain within themselves a measure of their own reliability. A coefficient of the reproducibility will yield a unique and useful measure of reliability.

4. The set of items will allow teachers to measure the degree of understanding of the content, and thus will add another dimension to the concept of content validity.

A Sample Set of Items

A basic communication presents the key term and a concise statement of the principle or generalization involved. The communication will not elaborate on the relationship. The purpose of this step is to bring the students to the "knowledge of term" and "knowledge of principle" level, i.e., recall or recognition without necessarily understanding. An example of this from an elementary science unit on light might be the following statement:

Objects look black if they absorb or soak up light.

The first item is a question measuring "knowledge of terminology" and requires only the recall or recognition of the term without understanding, as follows:

The word absorb means to

*1. soak up.
2. bend back.
3. scatter.
4. separate.

The second item measuring "knowledge of principle" requires only the recall or recognition of the principle and does not require understanding. The following is an example:

An object which absorbs light will look

*1. black.
2. white.
3. its true color.
4. disappear from view.

A series of questions includes a set of data containing a generic code which the students will be required to solve. A basic hypothesis of this proposal is that the Taxonomy level of "comprehension" really involves the encoding process. A sample of this type of a communication follows. This particular example builds on the previous items involving light.

> A man placed a red ball, a green ball, and a blue ball under a red light. The red ball looked red, but the green ball and the blue ball looked black. He then changed the red light to a blue light. When the blue ball was placed under a blue light, it looked blue. However, when he placed a yellow ball and violet ball under the blue light, they looked black.

The third item is a question measuring the student's ability to form a generic code from the communication. It is hypothesized that this is the same process the Taxonomy lists as "comprehension." The question follows:

In view of the above experiment it seems that it can be said that objects placed under a colored light will look

*1. the color of the light if it is really that color; otherwise, it will look black.
2. the same color as the light.
3. the color formed by the mixing of the color from the light and the color from the object.
4. black.

The fourth item in a set is concerned with the "extrapolation" from the generic code. In this item there is no real change in the type of content used. The cognitive process involved is that of going beyond the particular set of data that has been given by the utilization of the generic code. It involves the utilization of no new data, and does not require the creation of a different problem situation. In most cases it involves the inductive process because all of the possible combinations of the data are not present. If all of the possible combinations of the data were present, then this becomes a deductive proposition.

The item that is used to illustrate the "extrapolation" level involves the utilization of a generic code. The code is used to infer the way a ball of a different color from those used in the communication will look under a light of a different color from those used in the experiment.

If a violet ball is placed under a green light it will appear

*1. black.
2. green.
3. red
4. white.

The fifth item in a set is concerned with the "application" of the principle or generic code to general problem situations which are different from the situation in which the data was collected and encoded. This involves the concept of "transfer" and requires that the student recognize the identical components in the two situations, i.e., the situation in which the generic code was formed and the problem situation. A question requiring the "application" of the principle and/or generic code follows:

A woman, who is preparing a Halloween party, wants her many colored room to look orange and black. She has many orange colored things in her room. She can make her room look orange and black by using

*1. an orange light.
2. a black light.
3. yellow and brown lights.
4. red lights.

The sixth item deals with "analysis." Different questions are designed to measure the student's ability to analyze a communication in terms of its elements, relationships and organizational principles.

Included under "analysis of elements" are such things as (a) the ability to recognize unstated assumptions; (b) skill in distinguishing facts from hypotheses; (c) the ability to distinguish factual from normative statements; (d) skill in identifying motives and in discriminating between mechanisms of behavior with reference to individuals and groups; and (e) ability to distinguish a conclusion from statements which support it. The question following would seem to require that the student "analyze" the communication in terms of its elements. In this question, the student must realize that the experiment did not exhaust all of the possible combinations of light and ball color. The student has to realize that any generalization derived from such an experiment must of necessity be inferential. The question follows:

> After viewing the above experiment, a man concluded that a pink ball placed under a violet light would look black. He is

*1. probably right.
2. right
3. probably wrong.
4. wrong.

Included under "analysis of relationships" are (a) skill in comprehending the interrelationships among the ideas in the passage; (b) ability to recognize what particulars are relevant to the validation of a judgment; (c) ability to recognize which facts or assumptions are essential to a main thesis or to support the argument in support of that thesis; (d) ability to check the consistency of hypotheses with given information and assumptions; (e) ability to distinguish cause-and-effect relationships from other sequential relationships; (f) ability to analyze the relations of statements in an argument, to distinguish relevant from irrelevant statements; (g) ability to detect logical fallacies in arguments; and (h) ability to recognize the causal relations and the important and unimportant details in a historical account. The question below requires the student to be able to "analyze" the communication in terms of the relationships involved. To answer this question the student must analyze the communication for both the implicit and explicit relationships.

> After viewing the above experiment, a man concluded that colored objects reflect light. This statement is

*1. partially right.
2. correct.
3. incorrect; they diffuse light.
4. incorrect; they absorb light.

The "synthesis" level of the Taxonomy is not included in the sample items. This is because "synthesis" as defined by the Taxonomy involves, "The putting together of elements and parts so as to form a whole." "Synthesis" is concerned with the production of unique communication, plans or operations, and/or sets of abstract relations.

The seventh item in the set we have called "synthesis." However, the items we have constructed are not without faults, and may just require an extended "analysis." Characteristically, the items labeled "synthesis" have tended to require the student to analyze the experiment and then recognize either the next question to be asked or the next experiment which should be performed.

The eighth item is written in a manner to conform with "evaluation." These questions of necessity require the development of a problem situation to which the student is required to respond. This response can be in terms of "internal evidence" or "external criteria." The "external criteria" in this case is the ball experiment.

The following situation requires that the student recognize when a statement is consistent or inconsistent with experimental evidence and also that he be able to relate the statement to a different problem situation.

> A man, whose suit is really green, committed a murder in the Spectrum Club (a night club which has seven rooms each containing a different colored light of the spectrum). The murder was committed in the yellow room. The murderer then ran through the violet, green, red, orange and blue rooms. The witnesses, who actually saw the murderer running through the five rooms, responded as follows:
>
> Witness "A", in the violet room, said the man had on a red suit.
> Witness "B", in the green room, said the man had on a green suit.
> Witness "C", in the red room, said the man had on a blue suit.
> Witness "D", in the orange room, said the man had on a black suit.
> Witness "E", in the blue room, said the man had on a white suit.

Inspector "A" after looking at the data regarding the way the colored balls looked under the two different colored lights decided that witness "D" was telling the truth, and arrested the only man in the club wearing a black suit.

ASSUME THAT THOSE WITNESSESS MAKING TRUE STATEMENTS ARE TELLING THE TRUTH.

The best conclusion that can be reached is that the inspector was

*1. right--when he said witness "D" was telling the truth, but wrong when he arrested the man in the black suit.
2. wrong--when he believed witness "D", but right when he arrested the man in the black suit.
3. right--when he believed witness "D", and right when he arrested the man in the black suit.
4. wrong--when he believed witness "D", and wrong when he arrested the man in the black suit.

The next situation requires that the student realize that the conclusion arrived at from the ball experiment is inductive, and therefore only yields a probability statement. This probability statement must then be related to the problem situation.

Inspector "B", who had also seen the above experimental data, released the man in the black suit and arrested the only man in the club with a green suit. He is consequently brought to trial. You are on the jury. The prosecuting attorney sighting the experiment says that this proves that the man in the green suit committed the murder. In view of this evidence, and assuming that no clothing had been changed, and that no one had left the club, you should think that the man in the green suit

*1. probably committed the murder.
2. committed the murder.
3. is innocent.
4. probably did not commit the murder.

The final "evaluation" situation requires that the student examine a logically consistent argument, and then evaluate it in terms of external criteria, i.e., the ball experiment.

The attorney for the defense of the man in the green suit argues that the prosecution has five witnesses who saw the murderer running through the Spectrum Club, and that none of the witnesses agreed about the color of the man's suit. Therefore, he argues, it is impossible to say who committed the murder. This argument is

*1. logically presented, but disregards the experimental evidence.

2. not logically presented, but consistent with the experimental evidence.
3. Logically presented, and consistent with the experimental evidence.

Ideally, the "evaluation" item should require the student to select the best solution based on the criteria from among the alternative solutions, all of which provide essentially correct answers to the problem. This type of item was found very difficult to construct and requires a highly generalizable principle which has application in many problem situations. It was found that requiring an "evaluation" item for each set was so limiting that we stopped requiring it for the completion of a set.

RESULTS

Thirty one principles were used as the basis for the construction of the thirty one item sets - see Appendix A. The item sets were administered to secondary school students, and their reproducibility coefficients determined. The reproducibility coefficient is concerned with how well - knowing an individual's total test score on a particular item set - it is possible to predict which items in the set the individual answered correctly. The probability of the prediction of the correct items within a set is closely related to the difficulty of the set. Menzel[9], constructed a coefficient of scalability which is an attempt to adjust for the difficulty factor. The scalability and reproducibility coefficients are effected by the homogeniety of the subjects tested. The data on the reproducibility and scalability of the item sets are included in Table I.

TABLE 1

SUMMARY OF ITEM DATA

Item Set Number	Principle Tested	Number of Subjects	Grade Level of Subjects	Reproducibility Coefficient	Scalability Coefficient
1	Relationship of Amps, Ohms and Volts	63	12	.89	.80
2	Relationship of Amps, Ohms and Watts	63	12	.91	.62
3	Simple Lever	63	12	.92	.70
4	Separation of White Light	63	12	.83	.60
5	Relation of Volume of a Gas to Temperature	63	12	.92	.52
6	Relationship of Temperature to Pressure	339	9	.82	.43
7	Dissolving Time	339	9	.82	.45
8	Period of a Pendulum	339	9	.75	.19
9	Work	339	9	.76	.14
10	Refraction of Light	339	9	.85	.54
11	Relation of Color and Temperature	339	9	.89	.23
12	Altitude and Air Pressure	339	9	.80	.34
13	H_2O Displacement by Floating Objects	275	7	.82	.23
14	H_2O Displacement by Submerged Objects	275	7	.80	.14
15	Buoyance	275	7	.81	.35
16	Relationship of Velocity to Pressure	275	7	.82	.50
17	Gravitational Acceleration	275	7	.78	.27
18	Elasticity	275	7	.80	.31
19	Force and Motion	108	9	.88	.59
20	Center of Gravity	108	9	.85	.47
21	Gravitational Attraction	108	9	.88	.53
22	Dissoloving and Freezing	108	9	.87	.55
23	Electro-magnetism	108	9	.85	.50
24	Heat and Expansion	108	9	.79	.21
25	Windlass	105	9	.81	.40
26	Density and Refraction	105	9	.85	.54
27	Temperature and Evaporation	105	9	.80	.38
28	Dominant and Recessive Traits	105	9	.78	.20
29	Mendel's 3 to 1 Ratio	105	9	.87	.66
30	Hydraulic Pressure	105	9	.83	.37
31	Reflection of Colored Light	105	9	.85	.50

DISCUSSION

The reason for attempting to construct the sets of highly reproducible items was to provide an instrument which can be used to investigate the relationship between content and process. The item sets which were constructed are generally highly reproducible and seem to the writer to hold content constant and systematically vary process about as well as it can be done under the present rationale.

The item sets constructed were generally highly reproducible and moderately scalable. The correlation matricies which result when the different classes of items were correlated generally form a simplex. In a simplex the higher correlations are found along the main diagonal and the correlations then decrease in size as they approach the corners of the matrix. In nearly all cases adjacent item types correlate more highly with each other than with item types that are further away in terms of the psychological process involved. The relative difficulty levels of the items representing the Taxonomy classes lends support to the Taxonomy rationale – the "knowledge" level items are the easiest and items become progressively more difficult in each successive classification. All of the above conditions support the contention that the major classes constitute a cumulative and hierarchial continuum of psychological processes.

There are two ways that the item sets can be analyzed. In using coefficients of reproducibility and scalability, item sets are analyzed across people. A second way of examining this approach to measurement is to analyze people across items. Analyzing people across item sets provides some information regarding the relationship between the content and process used in answering the items. At the present time, there seems to be no adequate way of analyzing people across item sets. An examination of the data across people seems to indicate that the content and the process involved in answering the questions are inextricably entwined – at least under the present rationale. A particular student typically achieves different Taxonomy levels on item sets involving different content. This condition would seem to indicate that content is the more important of the two variables, and that "process," while it plays an important part in obtaining the correct answer is dependent upon content.

The item sets as they are constructed appear to be of more use to educational research than to the classroom teacher. It is possible to build item set upon item set in a manner similar to that of programed learning. The item sets can be logically connected to each other through "synthesis" items which require the student to determine either the next question to be asked or the next experiment to be performed. Following this procedure it may be possible to construct items that parallel the structure of the disciplines.

Item sets which attempt to hold content constant and systematically vary process are extremely difficult to construct. The construction of the item sets may only be feasible in the more advanced sciences. The items sets typically require a powerful and highly generalizable principle. The principle is powerful to the extent that it can be used to generate large quantities of factual data, and it is generalizable to the extent that it is applicable to the solution of many different types of problems. "Extrapoation" items in the set require the utilization of powerful principles while the "application" items require that the principle be highly generalizable.

The communication that accompanied the item sets contained experimental data which if properly encoded by the student leads to the principle upon which the item set is based. It was generally found that the difficulty of the "comprehension," "extrapolation" and "application" items was highly related to the nature of the principle involved. Students found no difficulty in encoding simple direct or inverse relationships such as: the rate of disolving increases with the amount of surface exposed; ampheres multiplied by ohms equals volts; or time, speed relationships. However, encoding, "extrapolating" and "applying" principles in which a variable increases or decreases as the square of another variable is very difficult. For example, falling objects, the period of a pendulum, or acceleration due to a constant force were difficult item sets. In the sets the lowest level of process was conceived to be the encoding of the data. Apparently the process of encoding can be at any level of difficulty depending upon the number of variables involved and the complexity of the relationship between them.

The item sets were typically very easy at the lower levels – "knowledge of term" and "knowledge of principle". The next four items in the set, "interpretation," "extrapolation," "application," and "analysis" provided most of the discrimination found in the sets. The "synthesis" and "evaluation" and to some extent the "analysis" items were too difficult for the great majority of the students. This was one of the greatest problems in constructing the item sets. Typically, it was necessary to build the item sets around very simple direct or inverse relationship concerned with not more than three variables. When more complex principles were used, higher level items became so complex that they were beyond the level of secondary school students. It is suggested that the extreme difficulty of the higher level items stems from the following:

(1) The inability of the item writers to hold content constant and systematically vary process – higher level items seem inevitably to require more and more information in addition to that found in the communication i.e., an understanding of the scientific method and the rules of logic.

(2) Failure of the typical secondary school curriculum to provide learning experiences which are designed to bring students to these higher levels of performance.

(3) The student's lack of familiarity with test items which measure the higher cognitive processes.

CONCLUSIONS, IMPLICATIONS, (and RECOMMENDATIONS)

Conclusions

Item sets of the type suggested in this study can be constructed. The item classes utilized in the construction of the item sets seem to be hierarchical and inclusive. Evidence of the hierarchical and inclusive nature of the item sets is indicated by the relative difficulty levels of the items within the sets, the simplex formed when the item classes are inter-correlated and the reproducibility and scalability coeffecients of the item sets. It should be mentioned that the methods used to empirically check the validity of the item classifications provide necessary but not sufficient data for the validation of the rationale. Other taxonomies of educational objectives based on a different rationale could also be constructed. These other taxonomies might postulate a different cumulative and heirarchical structure of educational objectives. Such taxonomies could very well be validated in the same manner as these item sets.

Implications

Item sets of the type that were constructed appear to be useful for demonstrating to educators different types of educational objectives, and as research tools for the purpose of empirically investigating the relationships between the different classes of objectives (item types). The item sets do not seem to be too useful for evaluating instruction as it generally exists today. This is because (1) the item sets are too difficult to construct and (2) the item sets that build from any but the very simplest principles become so difficult at the higher levels that almost no one can answer them. This is perhaps because the typical curriculum contains very few instructional experiences that are designed to bring students to the point where they can "analyze", "synthesize," and "evaluate."

It is probably possible to construct other cummulative and hierarchical taxonomies of educational objectives in which the items (1) increase in difficulty with each level and (2) are highly reproducible and scalable.

Educators generally agree that there are many different kinds of educational objectives. Whether or not the classification schema represented by the item sets is the best approach or not remains a question. There is some indication that the rationale upon which the item sets were based is more appropriate for sciences than for disciplines like language arts, philosophy of history.

Recommendations

Educators generally agree that a theory of instruction must necessarily be concerned with the concepts of generalization, transfer, analysis, synthesis and evaluation. The development and refinement of item sets that hold content constant and systematically vary process would seem to be essential for the development of a theory of instruction that is concerned with higher level cognitive processes. Questions remain regarding what these processes are, how precisely they can or ought to be defined, and how they relate to different kinds of content.

Characteristically we invent ways of classifying the objects and events in the world around us. We invent them for the purpose of ordering nature in a manner which will allow us to predict and control it. If a classification system adds to our ability to predict and control nature we retain it, otherwise, we typically reject it. The item sets that were constructed represent a way of classifying educational behaviors or goals. They are the criterion to be predicted, and as such represent value judgements regarding the desirability of educational goals. The worth of the item sets must ultimately depend upon (1) how closely their rationale corresponds to the manner in which meaningful verbal learning takes place and (2) how closely the abilities incorporated into the item sets correspond to those necessary to get along in the society.

Any item sets representing types of educational objectives would be more palatable if they were consistent with learning theory. The item sets that were constructed reflect a system for classifying educational objectives, and is not a classification of types of learning. Nevertheless, the usefulness of the classification system is necessarily related to the degree to which the rationale used conforms to the way meaningful learning takes place. This type of evaluation is necessarily limited by the stateoof development of learning theory which is itself in its infancy.

The second method of determining the worth of any taxonomy of educational objectives is by attempting to determine how closely the abilities incorporated into item sets representing the taxonomy correspond to those necessary to get along in society. At the present time, there is very little agreement as to what these abilities are. It was probably this realization that caused the authors of the Taxonomy to conclude that the worth of the classification system would ultimately be determined by its use. The construction of item sets in which an attempt is made to hold content constant and systematically vary process would seem to be one possible approach to the problem of isolating relatively independent measurable aspects of process.

In the writer's opinion, any workable theory of instruction must necessarily be concerned with the concepts of "transfer," "analysis" and "synthesis." The worth of any taxonomy of educational objectives must ultimately be related to the measurability of the cognitive processes involved. The item sets represent theorized processes which are not independent. At the present time, the psychological distance between the various levels cannot be adequately measured. Content to a large extent masks the effect of process. The problem, however, appears to be basic to a workable instuctional theory. Relating methods of instruction to types of objectives is an essential aspect of such a theory.

SUMMARY

Educators have begun to reorganize the elementary and secondary school curriculum. The "new" curricula is based upon a reorganization of the content of the disciplines in a manner that emphasizes their structure. A basic tenant of the "new" curricula is that teaching the structure of a discipline (1) makes a subject more comprehensible (2) facilitates retention (3) is the main road to adequate "transfer of training" and (4) narrows the gap between "advanced" knowledge and "elementary" knowledge.

Educators generally agree that any adequate theory of instruction must incorporate concepts such as transfer, analysis, synthesis and evaluation. Approaches to measurement have not, however, been adjusted to the "new" conception of the disciplines.

A workable theory of instruction would seem to depend upon the development of measurement instruments which operationally define these concepts in a manner which will make it possible to empirically investigate the relationships of methods of instruction and learner variables to the attainment of different types of educational objectives.

The project is concerned with the development of reproducible sets of test items in the physical sciences. The item sets were generally based upon the rationale of The Taxonomy of Educational Objectives: Cognitive Domain. In constructing the item sets an attempt was made to hold content constant and systematically vary the cognitive process involved in answering the items. Each item set contained seven or eight multiple choice items which were related to a communication. The communication consisted of two or more concepts and their definitions which make up a physical science principle, as well as a set of hypothetical experimental data which if properly encoded by the student should enable him to comprehend and transfer the principle.

The first two items in the set belong to the Taxonomy category of "knowledge." More specifically, they are "knowledge of term" and "knowledge of principle." The knowledge of term items theoretically require that the individual be able to recognize the definition of one of the key concepts involved in the principle. The definition of the term and the principle are in the same form in which they were presented in the communication.

The third and fourth items within a set belong to the major Taxonomy class of "comprehension." The third item requires that

the individuals be able to recognize the principles developed by the communication in a reordered form. For this reason the item belongs to the subclass "interpretation." An attempt was made to equate "interpretation" with the process of encoding the data presented in the communication. The encoding of the data should enable the individual to "extrapolate" and reproduce the results which would be forthcoming if the experimental variables were combined in a different manner.

The fifth item in the set belongs to the major Taxonomy class of "application." Answering item five requires that the individual be able to recognize those characteristics of the problem situation which determine whether the principle will apply. The introduction of a new problem is the criterion utilized to discriminate between an "extrapolation" item and an "application" item.

Item six within the set is an "analysis" item. The "analysis items are generally concerned with the "analysis" of relationships within the communication or with the "analysis" of a statement in relation to the communication.

The seventh item in the set is a "synthesis" item. Characteristically, the items we have labled synthesis have tended to require the students to analyze the present experiment and then recognize either the next question to be asked or the next experiment to be performed. The synthesis to be performed is either in the formulation of a new hypothesis or the suggestion of a new experiment that should be performed in view of the origional communication.

The eighth item in the set belongs in the Taxonomy class of "evaluation." The "evaluation" item requires that the student evaluate the principle for use in a specific problem situation. Ideally, the "evaluation" item should require the student to select the best solution based on the criteria from among the alternative solutions, all of which will provide essentially correct answers to the problem. This type of item is very difficult to construct and requires a highly generalizable principle which has applications in many problem situations. Constructing the "evaluation" items was so difficult that we stopped requiring it for the completion of the set.

Thirty one item sets were constructed and administered to secondary school students. The reproducibility coefficients were determined for each item set. The item sets yielded reproducibility coefficients that varied from .75 to .95. Reproducibility is concerned with how well we can predict which items within a set an individual got right if we are given the individuals score on that set.

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APPENDIX A

SET I
(Amps x Ohms = Volts)

Bill arranged some electrical circuits to investigate the relationships among:

a. volts: the electromotive force for the circuit;
b. ohms: the resistance of the conductor to the flow of electrical current;
c. amperes: the amount of current flow through the conductor.

Bill used wires that were 4 inches in length and .01 inch in diameter, but made of different metals. He used a 30 volt battery for each circuit. Bill recorded the following information for the various circuits:

Kind of wire	Amperes	Ohms	Volts
copper	5	6	30
aluminum	3	10	30
silver	10	3	30

After examining this information, Bill concluded that the product of the current flow and the amount of resistance equals the amount of electromotive force.

1. An ampere is a measure of the

   A. electromotive force.
   B. resistance of a conductor to the flow of electrical current.
   C. amount of current flow through the conductor.
   D. amount of volts provided by the battery.

2. What relationship did Bill find?

   A. The current flow multiplied by the resistance of the conductor equals the electromotive force.
   B. The resistance of the conductor equals the current flow divided by the electromotive force.
   C. The resistance multiplied by the electromotive force equals the current flow.
   D. The current flow equals the resistance of the conductor divided by the electromotive force.

3. Which of the following is another way of stating the relationship that Bill found?

   A. Amperes multiplied by volts equals ohms.
   B. Amperes multiplied by ohms equals volts.
   C. Ohms divided by volts equals amperes.
   D. Amperes divided by volts equals ohms.

4. How many volts must a battery produce before it can cause a tungsten wire with a resistance of 2 ohms to carry 12 amperes of current?

   A. 6 volts
   B. 1.66 volts
   C. 30 volts
   D. 24 volts

5. A boy wanted to build a model house that had a miniature electric lamp. At the store he bought a lamp with a resistance of 1.5 ohms. He planned to use a 3 volt battery in the circuit. How many amperes will flow through the lamp?

   A. 2 amperes
   B. 4.5 amperes
   C. 0.5 amperes
   D. 1.5 amperes

6. Bill found the following formula in his textbook: A x V = W or amperes times volts equals watts. Which of the following statements expresses the relationship of resistance to the formula for watts found in the textbook?

   A. Resistance has no effect on the amount of watts in a circuit.
   B. Resistance has been considered in the measurement of the number of volts.
   C. Increasing the resistance reduces the amount of amperes in the circuit.
   D. Watts divided by resistance equals volts.

7. Bill decided to test further the relationship of amperes, ohms, and volts with the same three wire conductors. By doubling the number of volts passing through the conductors he found the following:

Kind of wire	Amperes	Ohms	Volts
aluminum	3.5	15	60
copper	6.7	8	60
silver	15.0	4	60

The information from Bill's second experiment does not appear consistent with results of his first experiment. To which of the following questions would a "yes" or "no" answer provide the most useful information to further explain the relationship of amperes, ohms and volts?

A. Would Bill's relationship break down for silver also if the number of volts is increased more?
B. After a certain number of volts is used, does Bill's relationship break down?
C. For any conductor in a circuit will Bill's relationship break down after a certain number of volts are used?
D. Does Bill's relationship remain the same for most metals if the number of volts is kept low?

SET II
(Ohms x Amps = Watts)

John wanted to investigate the relationships among the following measures:

a. current: the rate of electrical flow through a conductor, measured in amperes;
b. resistance: the ability of a conductor to slow down the flow of electricity, measured in ohms;
c. power: the time rate at which work is done, measured in watts.

To do this he set up three circuits, using different pieces of wire attached to the poles of a 30 volt battery.

He then measured the resistance, current and power and obtained the following data:

Wire	Ohms	Amperes	Watts per hour
1	.5	60	1800
2	5.0	6	180
3	15.0	2	60

After examining the data, John concluded that power equals resistance multiplied by the square of the current flowing through the conductor.

1. Power is the measure of

   A. the time rate at which work is done.
   B. the rate of electrical flow through a conductor.
   C. the ability of a conductor to slow down the flow of electricity.
   D. the electrical pressure in a wire, per unit time.

2. The relationship John found was that the power equals

   A. the current multiplied by the square of the resistance.
   B. the resistance multiplied by the current.
   C. the resistance multiplied by the square of the current.
   D. the square of the current and the resistance.

3. John's conclusion was that power equals resistance times the square of the current. Another way of stating this would be:

   A. Ohms times amperes equals watts.
   B. Amperes times ohms squared equals watts.
   C. Watts times amperes squared equals ohms.
   D. Amperes squared times ohms equals watts.

4. Another circuit is set up the same way. If the current flow is found to be 4 amps and the resistance to be 10 ohms, the number of watts per hour will be

   A. 160
   B. 40
   C. 1.6
   D. 400

5. A boy made an egg incubator from old materials around the house. He figured that if the resistance in the heater of the incubator was 3 ohms and the current 10 amps, the incubator would use _____ watts per hour.

   A. 90
   B. 9
   C. 30
   D. 300

6. John set up circuits attached to a 30 volt battery again. This time he measured resistance, current and temperature of the wire.

Wire	Ohms	Amperes	Temperature
1	3	10	106°F
2	6	5	97°F
3	10	3	85°F

   John examined the data from the two experiments. He wanted to figure out the relationship between heat generated in a wire and the power used, measured in watts. The best conclusion that he could make after examinig the above data is that the temperature of a conductor:

   A. is related to watts directly through the volts.
   B. is related to watts directly through the ohms involved in the formula for watts.
   C. is related to watts directly through the amperage involved in the formula for watts.
   D. is equal to the power.

7. The best question to ask in order to further establish the relationship between power and heat would be:

   A. Does greater power produce greater heat per unit time than lesser power?
   B. If voltage is increased, will watts change?
   C. If voltage, resistence and current are varied simultaneously, will watts increase?
   D. Are watts and heat related?

8. A toy manufacturer wished to set up the most efficient and economical means of joining pieces of rails on an electric railway. John suggested that he could place the two pieces of metal into contact with each other and pass a large current through the pieces, thus joining them. His idea was

   A. good - because the large current would heat the two pieces evenly, thus joining them.
   B. bad - because the cost of using the large current would be too great.
   C. good - because most of the energy available would be used to melt and join the rails.
   D. bad - because the entire rail would be evenly heated, thus wasting power.

SET III
(Simple Lever)

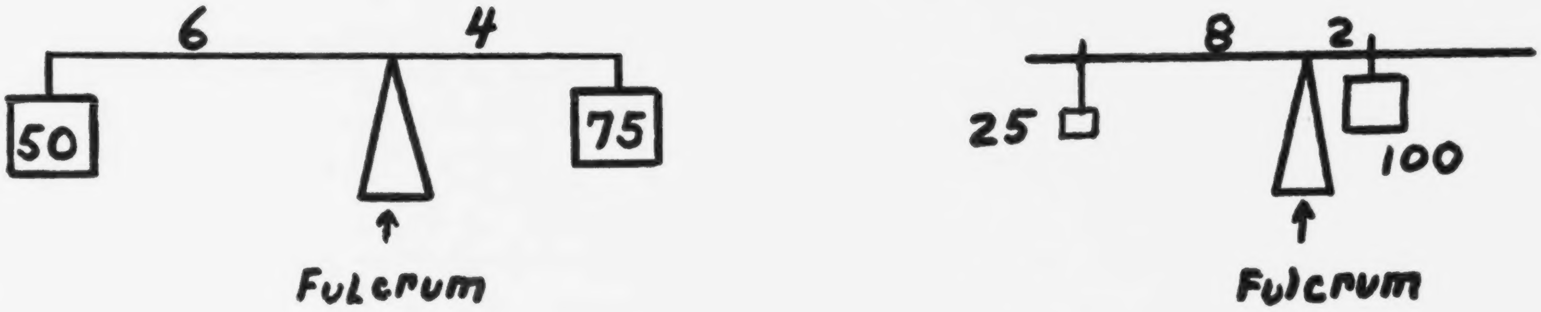


Figure I

John performed the following experiment using a fulcrum, a set of weights, and a ten foot rod. He wanted to make the rod balance when different weights were placed on the opposite ends. Figure 1 shows the arrangement of two experiments in which the rod balanced.

John concluded that if the product of the weight times the distance the weight is from the fulcrum (or support) is the same for both ends of the rod, then the rod will balance.

1. The fulcrum is the name for the

   A. weights used.
   B. the support for the lever.
   C. another name for the rod.
   D. the term used to describe the product of the two weights.

2. John's conclusion was that if the product of the weight times the distance the weight is from the fulcrum is the same for both ends of the rod, then

   A. the rod will tilt toward the heavier weight.
   B. the rod will tilt toward the lighter weight.
   C. the rod will balance.
   D. none of the above means the same as John's conclusion.

3. Suppose E is the force on one end of a lever, and DE is the distance between this force and the fulcrum. R is the force on the opposite end of the lever, and DR is the distance between R and the fulcrum. Which of the following statements is true on the basis of the information given in Figure 1?

A. E x DE = R x DR
B. E x DR = R x DE
C. E x R = DE x DR
D. R x DE = E x DE

4. Examine Figure 2. How far should the 10 pound weight be placed from the fulcrum so the lever is balanced?

A. 3 feet
B. 6 feet
C. 9 feet
D. 12 feet

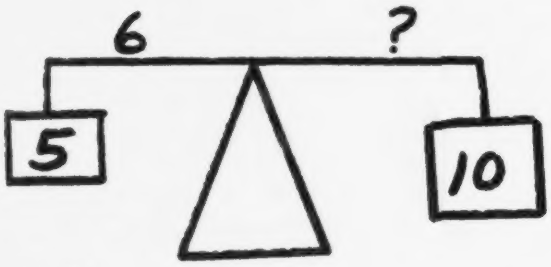


Figure 2

5. Johnny's two little sisters played on a see-saw with him. In order to balance the see-saw, his two sisters sat 3 feet from the fulcrum, and he sat 4 feet from the fulcrum on the opposite side. If each girl weighs 40 pounds, how much does Johnny weigh?

A. 30 pounds
B. 40 pounds
C. 50 pounds
D. 60 pounds

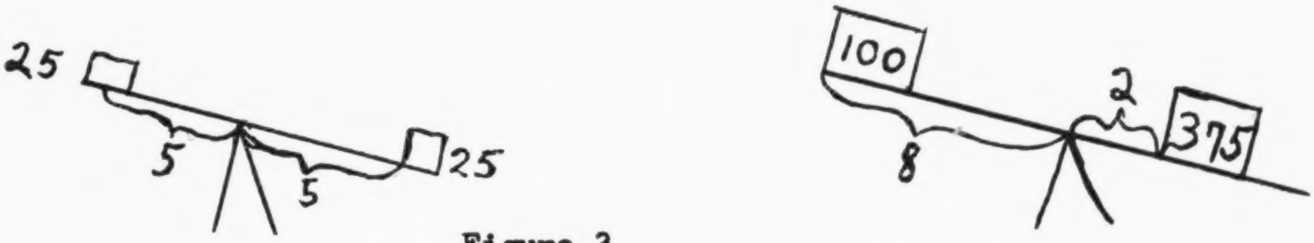


Figure 3

6. Johnny did some experiments with other levers. Figure 3 shows what he did and his results. On the basis of Figure 3 we can conclude that Johnny's results are not consistent with the information given at the beginning in Figure 1. To make his results consistent Johnny should consider

   A. the positions of the forces on the levers.
   B. the weight at the end nearest the fulcrum.
   C. the distance of the fulcrum from the center of the lever.
   D. the weight of the fulcrum.

7. To explain the inconsistency between the information given in Figure 1 and Johnny's results (Figure 3), you should

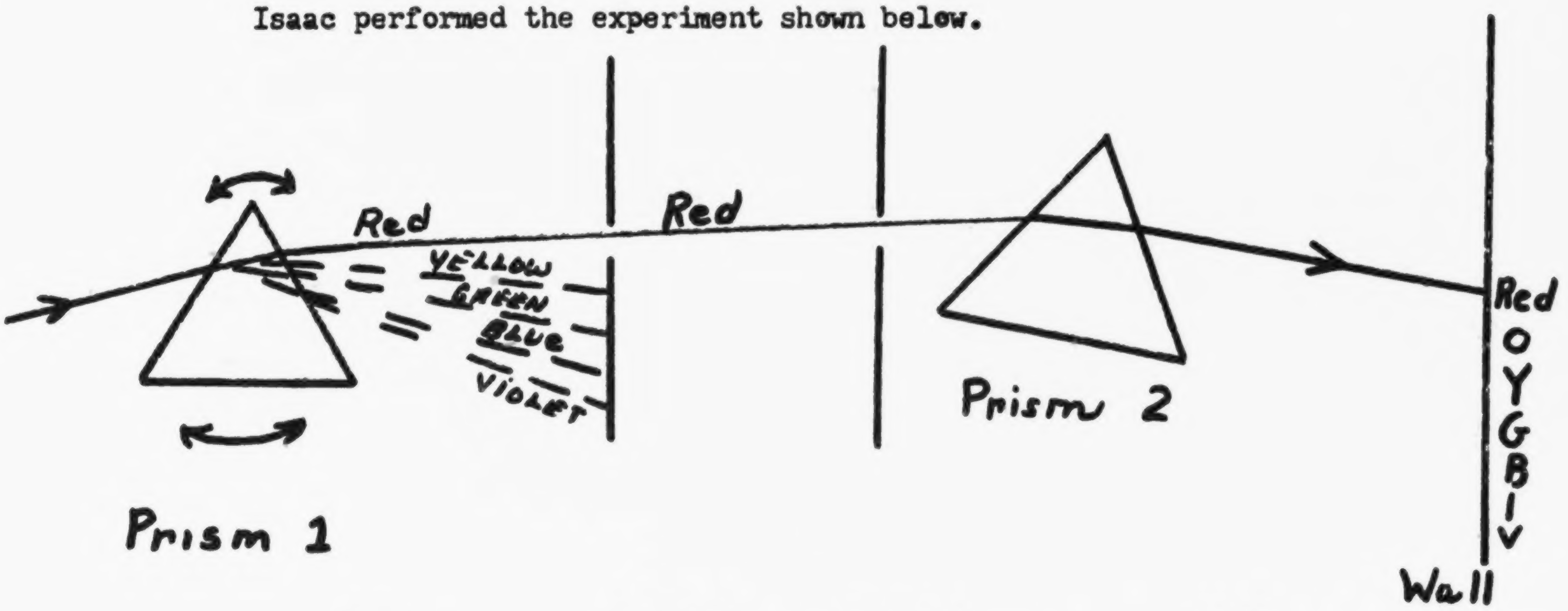
   A. ignore the results of Figure 3. They are obviously wrong.
   B. re-do the experiments shown in Figure 3 and give more attention to where the forces are placed.
   C. accept the results of Figure 3 as true and alter the ideas given in Figure 1.
   D. do a new experiment in which the weight of the fulcrum is measured.

8. A man said, "Give me a fulcrum and a lever long enough, and I can move the world with 1 pound of pressure." The man's statement

   A. is a contradiction of the principle.
   B. is theoretically possible if you consider that the lever has weight.
   C. is theoretically possible if the fulcrum is near enough to the earth.
   D. can't be true if the principle is true.
   E. is theoretically impossible because there is no place to put the fulcrum.

SET IV
(Separation of White Light)

Isaac performed the experiment shown below.



Prism 1 Board 1 Board 2 Wall

Isaac found that when he rotated the first prism, the different colors of the spectrum were caused to strike the second prism at the same angle and be refracted (or bent) onto the wall. Isaac observed where each beam of light fell. He then noted that each color of the spectrum was refracted to a different degree and struck the wall in a different place. He concluded that sunlight consists of different colored rays of the spectrum which are bent to different degrees when passed through the prism and which cannot be further broken down to produce other colors.

1. To refract means to

    A. bend.
    B. transmit.
    C. bounce back.
    D. absorb.

2. Isaac concluded that:

    A. Prisms create colored light.
    B. Sunlight is one kind of light.
    C. There are only six colors of light.
    D. Sunlight consists of different colored rays which are refracted to a different degree when passed through a prism.

3. Which of the following means the same thing as Isaac's conclusion?

   A. When sunlight is passed through a prism, the prism creates colored light in the form of a spectrum.
   B. The colors of the spectrum can be further broken down if passed through another prism.
   C. When sunlight is passed through a prism, the spectrum is caused by the differential bending of the various colored rays that make up white light.
   D. A circular spot of white light can be refracted to produce an oval spot of white light by passing it through a prism.

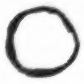
4. Passing a green light through a prism would cause what color or colors to appear on the wall?

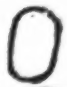
   A. Green
   B. Blue and yellow
   C. Yellow, orange, and red
   D. Violet and blue

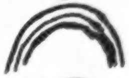
5. A man is building a machine for use in a carnival. The machine consists of a gun which fires a light beam through a glass prism at a target. If he wants to make hitting the target as difficult as possible, he should use which of the following light beams?

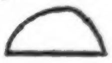
   A. Red
   B. Green
   C. Violet
   D. Blue and red
   E. It makes no difference.

6. If in an experiment a circular ray of sunlight enters a prism and the ray is projected onto the wall, the shape of the image projected onto the wall will be a

   A. 

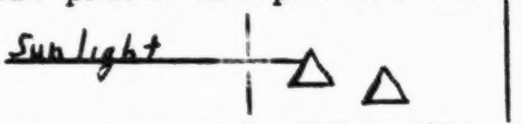
   B. 

   C. 

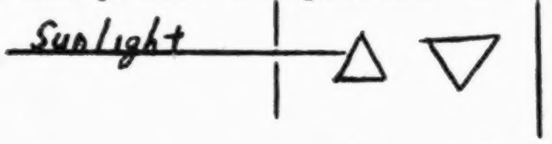
   D. 

7. In view of what Isaac has done, the most logical next step is to:

   A. Pass each individual color through a prism.
   B. Use two prisms and perform the experiment shown.



   C. Use two prisms and perform the experiment shown.



   D. Try to break red light down farther.

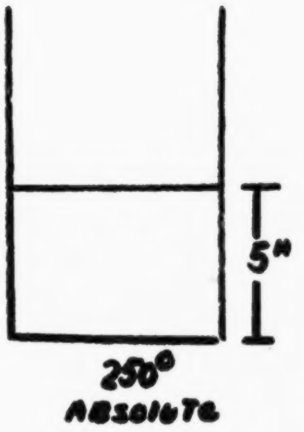
8. Issac proposed that a telescope be made out of one large convex lens (a lens which is thicker in the middle and thinner at the edges). This telescope

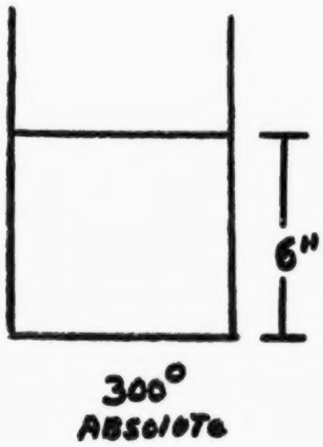
   A. will work.
   B. will produce a blurred image.
   C. won't work.
   D. would work with a concave lens.

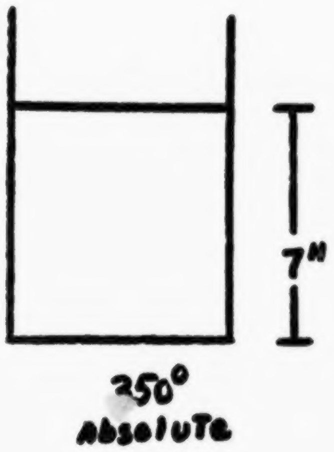
(Convex lens)

SET V
(Temperature and Volume)

Mary placed a volume of hydrogen in a sealed cylinder with a movable top. She then began to raise and lower the absolute temperature of both the cylinder and the gas. She assumed that the area of the base of the cylinder is 1 square inch, so that the volume of the gas is the height of the piston x 1.







From this data, Mary concluded that the volume - or amount of space occupied by the gas - increases directly as the absolute temperature of the gas increases.

1. Volume is the

   A. amount of space occupied by the gas.
   B. amount the piston rises.
   C. diameter of the cylinder.
   D. area of the cylinder.

2. According to Mary's conclusion, the volume of the gas

   A. is constant for a given sample of gas.
   B. increases as the temperature decreases.
   C. increases directly as the absolute temperature increases.
   D. decreases as the temperature decreases.

3. Another way of stating Mary's conclusion is:

   A. If the temperature increases, the volume will decrease.
   B. If the temperature increases, the volume will increase.
   C. The volume always remains the same for any sample of gas.
   D. If the volume increases, the temperature decreases.

4. If the temperature is 50° on the absolute scale, the volume of the gas in the original experiment would be

   A. 1 cubic inch.
   B. 3 cubic inches.
   C. 7 cubic inches.
   D. 10 cubic inches.

5. 100 cubic feet of helium are pumped into a weather balloon which is at 283° absolute. When the temperature changes to 333° absolute, the volume of the balloon will be

   A. 20 cubic feet.
   B. 90 cubic feet.
   C. 100 cubic feet.
   D. 110 cubic feet.

6. If V_1 is the volume of a gas at temperature T_1, and the volume of the gas is V_2 when the temperature changes to T_2, then, which of the following is consistent with the original principle?

A. $\frac{V_1}{V_2} = \frac{T_1}{T_2}$

B. $\frac{V_2}{V_1} = \frac{T_1}{T_2}$

C. $\frac{T_1}{V_1} = \frac{V_2}{T_2}$

D. $\frac{T_2}{V_1} = \frac{V_2}{T_1}$

7. In view of what Mary found, her next step should be to

   A. increase the quantity of gas in the cylinder.
   B. repeat her experiment using many different temperatures.
   C. increase the pressure on the cylinder and observe the temperature.
   D. get a larger cylinder and determine the relationship between temperature and volume.

SET VI

(Temperature and Pressure)

John placed a barometer, an instrument for measuring air pressure, in a sealed jar containing air. In order to determine if the air pressure, a measure of the force exerted by the air against the walls of the jar, is influenced by a change in temperature, he heated the air in the jar. He recorded the following information:

Temperature of the air in the jar	Air Pressure (pounds per square inch)
o	
50o	14.5
100o	15.0
150	15.5

John concluded that the pressure exerted by the air in a sealed container increases as the temperature of the air increases.

1. Air pressure is a measure of

   A. force.
   B. temperature.
   C. moisture.
   D. time.

2. John's conclusion was that the pressure exerted by air within a sealed container

   A. increases as the temperature of the air increases.
   B. decreases as the temperature of the air increases.
   C. increases as the temperature of the air decreases.
   D. remains the same regardless of the temperature of the air.

3. John's conclusion was that the pressure exerted by air in a sealed container increases as the temperature increases; another way of saying this is that:

   A. As the air temperature in a sealed container increases, the air pressure decreases.
   B. As the air pressure in a sealed container decreases, the air temperature increases.
   C. The air temperature in a sealed container is inversely proportional to the air pressure.
   D. The air pressure in a sealed container is directly related to the air temperature.

4. If John increased the temperature of the air in the sealed container to 200° F, then in view of the experiment, you would expect the air pressure in pounds per square inch to be

   A. 14.5.
   B. 16.0.
   C. 17.0.
   D. 16.5.

5. Four boys had balloons of the same size and filled with the same amount of air. The first boy put his balloon on the bed. The second boy put his balloon on the floor in the basement. The third boy laid his balloon on the living room floor in the sunlight. The fourth boy put his balloon in the hall closet. Which balloon is most likely to break? The balloon

   A. in the hall closet.
   B. in the basement.
   C. on the bed.
   D. on the living room floor.

6. Mike watched John conduct his experiment with the sealed jar and barometer. Afterwards Mike made the following statement: "If I increase the pressure on air, I will also increase its temperature." Which of the following is true in regard to Mike's statement?

   A. It is the same as John's.
   B. It is false if John's is true.
   C. It follows from John's but is not the same as John's.
   D. There is no evidence that Mike's is true if John is true.

7. The question to ask next to get the most information is:

   A. What would be the effect of allowing the volume to change as the temperature increases?
   B. What will happen if a metal container is used?
   C. Does the pressure decrease when the temperature decreases?
   D. Does the temperature increase if the pressure increases?

SET VII
(Dissolving)

John put lifesavers in 3 glasses of water. He found that they dissolved, or melted into the solution, after one hour.

He increased the surface area of some other lifesavers by breaking them into 3 pieces. When he put the 3 pieces from one lifesaver into a glass of water, he found that they dissolved in 40 minutes. After repeating the experiments several times, John concluded that when the surface area of the object is increased, the time it needs for dissolving decreases.

1. Dissolve means to

    A. break into pieces.
    B. increase surface area.
    C. melt faster.
    D. melt into the solution.

2. When the surface area of the object is increased

    A. the time it needs for dissolving increases.
    B. the time it needs for dissolving decreases.
    C. the volume of the object increases.
    D. the number of pieces decreases.

3. Another way of stating John's conclusion is that:

    A. The more pieces, the longer it takes to melt.
    B. The longer the dissolving time, the smaller the surface area.
    C. The smaller the surface area, the shorter the time it takes the object to go into solution.
    D. As the surface area gets larger, the object melts into the solution faster.

4. If the lifesavers were broken into 9 pieces, the dissolving time would be

    A. more than 1 hour.
    B. less than 1 hour but more than 40 minutes.
    C. 1/3 of the time for 3 pieces.
    D. less than 40 minutes but not necessarily 1/3 of 40 minutes.

5. A 50-lb. block of ice would melt the fastest if it were

   A. left in the block.
   B. cut into 1 inch cubes.
   C. cut into small spheres.
   D. crushed finely.

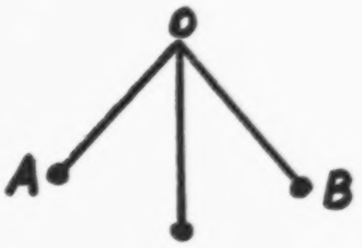
6. George says that a solid ice cube will cool a drink faster than one with a hole in it. His statement is:

   A. Consistent with the original conclusion if the surface area of the block is increased by drilling a hole in it.
   B. Inconsistent with the original conclusion if the surface area of the block is increased by drilling a hole in it.
   C. Consistent with the original conclusion only if increasing the surface area does increase the dissolving rate.

7. The next experiment that should be done is to

   A. dissolve objects with different surface areas and different weights and record the dissolving time.
   B. drill 1/2 inch holes in objects and record their dissolving time.
   C. use objects of different shpaes but with the same volume.
   D. dissolve like objects at different temperatures.

SET VIII
(Period of A Pendulum)



Jim made a pendulum by attaching a string to a fixed support (labeled O in the drawing) and then tying weights to the other end of the string. Keeping the angle labeled AOB the same but changing the length of the string, he recorded the data below. The period of the pendulum is the amount of time for the pendulum to make one complete motion back and forth (from A to B and back to A).

Length of the Pendulum	Period of the Pendulum
1 foot	1 second
4 feet	2 seconds
9 feet	3 seconds
16 feet	4 seconds

From the data Jim concluded that the period of the pendulum varies as the square root of the pendulum's length.

1. The period is the

   A. time for the pendulum to make one complete motion back and forth.
   B. length of the pendulum.
   C. time for the pendulum to go from one point to another.
   D. length of the path of the pendulum.

2. The period of the pendulum

   A. varies as the length of the pendulum.
   B. varies as the square root of the length of the pendulum.
   C. increases 1 second when 7 feet is added to the length.
   D. depends on the path of the pendulum.

3. According to Jim's conclusion:

   A. The longer the pendulum, the longer the period.
   B. The longer the pendulum, the shorter the period.
   C. The shorter the path, the shorter the period.
   D. The shorter the pendulum, the longer the period.

4. If the length of the string were 36 feet, the period would be about

   A. 6 seconds.
   B. 12 seconds.
   C. 18 seconds.
   D. 36 seconds.

5. A clock on the moon has a pendulum 16 feet long; its period is 2 seconds. If the length of the pendulum is changed to 100 feet, the period will be

   A. 1 second.
   B. 2 seconds.
   C. 5 seconds.
   D. 10 seconds.

6. John states that if angle AOB is increased, the period will not change. He assumes that

   A. air resistance increases as the angle increases.
   B. any change in the period because of the change in angle is so small he can't measure it.
   C. as the angle increased, the path of the pendulum increased.
   D. only the length of the pendulum affects the period.

7. The question Jim should ask to get the most information would be:

   A. Does the length of the pendulum affect the period?
   B. Does the amount of weight used affect the period?
   C. Does changing the location affect the period?
   D. Does the path of the pendulum affect the period?

SET IX
(Work)

Bob moved three barrels, all the same weight, into the storeroom. He lifted one barrel up to a shelf, dragged one across the floor, and rolled the last one across the floor. The amount of work, measured in foot-pounds, that he did when moving each barrel is given in the following data:

Weight of barrel	Method of moving	Effort used to move it	Distance effort was exerted	Amount of work
50 lbs.	lifting	50 lbs.	5 feet	250 fp.
50 lbs.	dragging	25 lbs.	5 feet	125 fp.
50 lbs.	rolling	10 lbs.	5 feet	50 fp.

The amount of work done is the product of the effort (the number of pounds necessary to move the resistance) times the distance which the effort is exerted.

1. Effort is

   A. amount of work done.
   B. distance the force is exerted.
   C. weight of the barrel.
   D. number of pounds necessary to move the resistance.

2. The amount of work done is equal to the product of

   A. the weight of the object times the effort used to move it.
   B. the effort times the distance over which the effort is exerted.
   C. the weight of the object times the distance the effort is exerted.
   D. the distance over which the work is done times the weight of the object.

3. If E equals the amount of effort exerted and DE equals the distance over which the effort is exerted, another way of stating how to find the amount of work W is:

   A. W = E x DE.
   B. W x E = DE.
   C. E = W x DE.
   D. W = E x E x E.

4. If Bob does 45 foot-pounds of work in lifting a box 3 feet straight up, how much effort did he exert?

   A. 125 pounds
   B. 75 pounds
   C. 15 pounds
   D. 5 pounds

5. Two children are playing on the seesaw. If one boy weighs 75 lbs. and is lifted 4 feet into the air, how much work did the 50 lb. boy accomplish?

   A. 8 fp.
   B. 200 fp.
   C. 300 fp.
   D. 450 fp.

6. An automobile does the most work when

   A. it runs steadily on the level at a constant speed.
   B. the car begins to move on level ground.
   C. the car speeds up on an upgrade.
   D. the car slows down going down a hill.

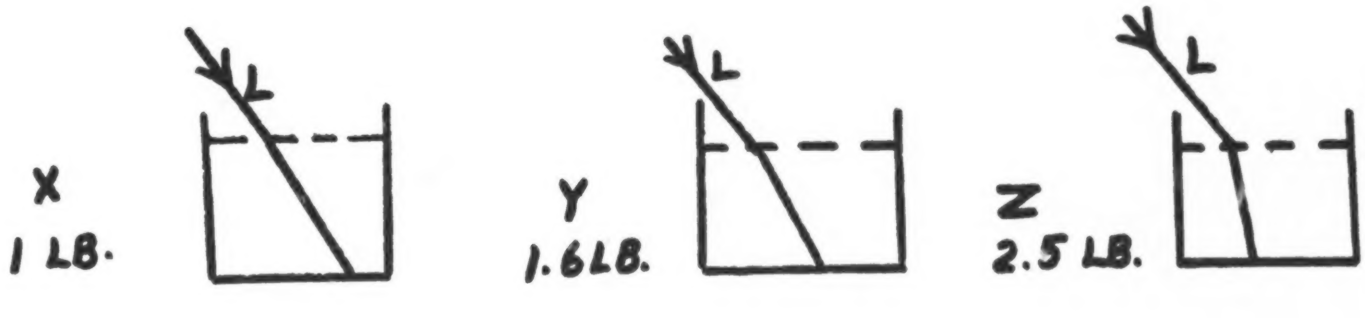
7. In view of the experiment performed the best question to ask next is:

   A. Will the kind of surface on which the object is moved change the amount of work done?
   B. Is time a necessary factor in the accomplishment of work?
   C. Can work be accomplished without using energy?
   D. If the force is doubled, how will this affect the amount of work accomplished?

SET X
(Refraction of Light I)

Because light travels at different speeds in different substances, it is refracted (bent) when it goes from one substance to another.

Three containers are filled with equal amounts of 3 liquids. The weight for the liquid in each container is given below the figure.



L represents a ray of light in the air and its path when it goes into the liquid. Dave observed the above experiment and concluded that the heavier the liquid, the more the light ray is refracted.

1. To refract means to

   A. bounce back.
   B. scatter.
   C. pass through.
   D. bend.

2. The heavier the liquid, the

   A. more the light ray is refracted.
   B. less the light ray is refracted.
   C. faster light goes through it.
   D. better it transmits light.

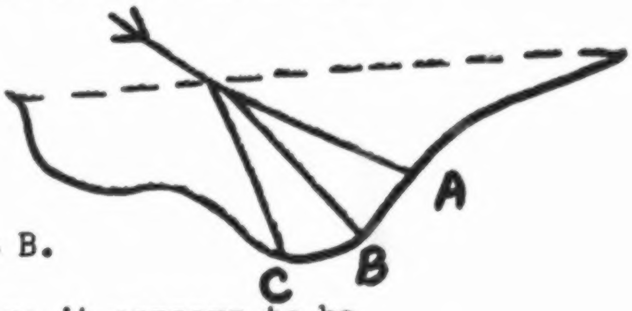
3. A heavy liquid will refract a light ray

   A. more than a light liquid.
   B. less than a light liquid.
   C. the same as a light liquid.
   D. in an amount unrelated to the light liquid.

4. A container the same size and shape as those in the original experiment is filled with light transparent oil, which weighs 0.6 lb. It will refract light

   A. more than the three liquids X, Y, and Z in the original experiment.
   B. less than the three liquids X, Y, and Z in the original experiment.
   C. more than X but less than Y and Z.
   D. more than X and Y but less than Z.

5. Jerry is looking into a pond. He thinks there is a rock at B. The rock is actually at



   A. A.
   B. B.
   C. C.
   D. It could be at A or C but not at B.

6. Joe said, "The sun is not really where it appears to be at sunset." This statement is

   A. true- it will appear above where it really is.
   B. true- it will appear below where it really is.
   C. false- because air isn't a liquid.
   D. false- because air doesn't bend light.

7. The next experiment that should be done in view of the original experiment is to

   A. put nontransparent liquids in the containers.
   B. use containers made of different materials.
   C. use different amounts of liquids.
   D. vary the temperature of the liquids in the original experiment.

SET XI
(Color and Temperature)

Sue had pieces of dark blue, medium blue, and light blue paper. She placed one piece of each in the sun, put a thermometer under each one, and left them for 1 hour. She then recorded the temperature of each one.

Color	Temperature after 1 hour
Light blue	70° F
Medium blue	75° F
Dark blue	90° F

From this experiment Sue concluded that dark colored materials absorb (take in) more heat than light colored materials.

1. To absorb means to

   A. take in.
   B. scatter.
   C. reflect.
   D. disappear.

2. Dark colored materials

   A. absorb less heat than light colored materials.
   B. absorb more heat than light colored materials.
   C. reflect more heat than light colored materials.
   D. reflect all heat.

3. The lighter the color,

   A. the more heat is absorbed.
   B. the less heat is absorbed.
   C. the faster heat is absorbed.
   D. the higher the temperature.

4. White paper will absorb

   A. more heat than light blue but less than dark blue.
   B. less heat than light blue.
   C. more heat than dark blue.
   D. the same amount of heat as dark blue.

5. On a hot summer day the best color of clothes to wear would be

   A. light green.
   B. medium green.
   C. dark green.
   D. The color makes no difference.

6. Butch said, "My black wool jacket will be warmer than my black leather jacket on a calm sunny day." What has he assumed?

   A. Only the color of the material affects the warmth.
   B. Black absorbs heat rapidly.
   C. Texture of the object affects the amount of heat absorbed.
   D. Temperature affects the amount of heat absorbed.

7. In view of the experiment Sue did, what is the best question to ask next?

   A. Does changing the surface area of the object change the temperature?
   B. Does changing the shades of color change the temperature?
   C. Does changing the texture of the object affect the temperature?
   D. Does changing the shape of the object change the temperature?

SET XII

(Altitude and Air Pressure)

A mercury barometer is an instrument used to measure air pressure. The height of the column of mercury is an indication of the amount of air pressure due to the weight of the air. Some sample measurements of air pressure at various altitudes, the distance above sea level, are given below:

Number of feet above sea level	Heights of mercury column in inches
0	29.90
1000	29.80
2000	29.70
3000	29.60

According to these readings we may conclude that as the altitude increases, the amount of air pressure decreases.

1. Altitude is

   A. air pressure.
   B. distance above sea level.
   C. air temperature.
   D. height of the column of mercury.

2. According to the conclusion:

   A. As the altitude decreases, the amount of air pressure decreases.
   B. As the amount of air pressure increases, the altitude increases.
   C. As the altitude increases, the amount of air pressure decreases.
   D. Air pressure does not change with a change in altitude.

3. Another way of stating the conclusion is:

   A. The column of mercury rises when the temperature goes down.
   B. The column of mercury rises with an increase in altitude.
   C. The column of mercury falls when the altitude goes up.
   D. The column of mercury remains the same regardless of changes in altitude.

4. If a barometer reading was taken at 4000 feet above sea level, on the basis of the given data the reading would be

   A. 29.60.
   B. 29.50.
   C. 29.40.
   D. 29.30.

5. Water will boil when its vapor pressure is equal to the air pressure over its surface. Therefore, a family living on Pike's Peak must take altitude into consideration when cooking. If potatoes are boiled there, they will cook

   A. faster than they would at sea level.
   B. slower than they would at sea level.
   C. at a higher temperature than they would at sea level.
   D. the same as they would at sea level.

6. Mr. Jones lowered a large glass jar over a cup of very hot coffee. In a few minutes the coffee started to boil. He let it boil for a minute. When he removed the jar, the coffee stopped boiling immediately. What may Mr. Jones conclude, as a possible explanation?

   A. The air pressure within the jar was higher than the atmospheric pressure surrounding the jar; and therefore, boiling was able to occur at a lower temperature than usual.
   B. The air pressure within the jar was lower than the atmospheric pressure surrounding the jar; and therefore, the boiling point of the coffee was lower than usual.
   C. The air pressure within the jar was higher than the atmospheric pressure surrounding the jar; and therefore, the boiling point of the coffee was higher than usual.
   D. The temperature of the coffee increased as the pressure within the jar increased.

7. Which of the following would be the best question to investigate next?

   A. Are barometer readings similar for all cities at sea level?
   B. Does air pressure decrease with altitude?
   C. Does air pressure increase with an increase in altitude?
   D. Does a change in relative humidity have an effect on air pressure?

SET XIII
(Displacement: Floating Objects)

Archey performed an experiment. He filled an overflow can (See Figure A below) up to the spout with water. He then placed a 1000 cubic centimeter pine block weighing 800 grams into the can and recorded both the distance the wood sank into the water and the weight of the water that ran out the overflow. He then removed the block of wood, refilled the can, and placed a 1,000 cubic centimeter cork weighing 220 grams into the can, and recorded the same information. He repeated this procedure with 1000 cubic centimeter blocks of other materials and recorded his results as shown below:

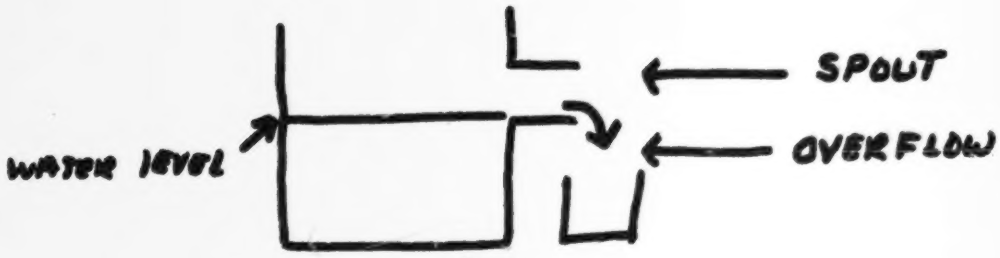


Fig. "A"

1000 cc. blocks	Block sank or floated	% of block below the water	weight of the block	weight of water overflowing
Pine	floated	80%	800 grams	800 grams
Cork	floated	22%	220 grams	220 grams
Oak	floated	95%	950 grams	950 grams
Brass	sank	100%	8400 grams	1000 grams
Lead	sank	100%	16000 grams	1000 grams

After studying his results Archey concluded that a floating object sinks into a liquid until it displaces, or shoves out of the way, an amount of liquid equal to its own weight.

1. To displace means to

    A. sink.
    B. buoy up.
    C. shove out of the way.
    D. float.

2. Archey's conclusion was that a floating object

    A. floats until it displaces an amount of liquid equal to its own weight.
    B. floats when the amount of liquid displaced is less than the weight of object.
    C. sinks until it displaces an amount of liquid equal to its own weight.
    D. sinks until the amount of liquid displaced is greater than the weight of the object.

3. Archey concluded that a floating object sinks into a liquid until it displaces an amount of water equal to its own weight. Another way of saying this is:

    A. When the liquid is displaced, the floating object will sink until the amount of liquid displaced equals the weight of the object.
    B. When liquid is displaced, the floating object will sink until the amount of liquid displaced is greater than the weight of the object.
    C. If the weight of the object is greater than the weight of the liquid displaced, the object will sink.
    D. If the weight of the displaced liquid equals the weight of the object, the object will float.

4. A ping pong ball weighs 2 grams. If it is placed in the overflow tank, the number of grams that will overflow is

    A. 4 grams.
    B. 2 grams.
    C. 1 gram.
    D. 0.5 grams.

5. A barge which weighs 20,000 lbs. is filled with 10,000 lbs. of coal. The barge will sink into the water until it has pushed aside

   A. 10,000 lbs. of water.
   B. 20,000 lbs. of water.
   C. 30,000 lbs. of water.
   D. 2,000 lbs. of water.

6. Archey says, "Rocks won't float." Which of the following statements has he accepted as true?

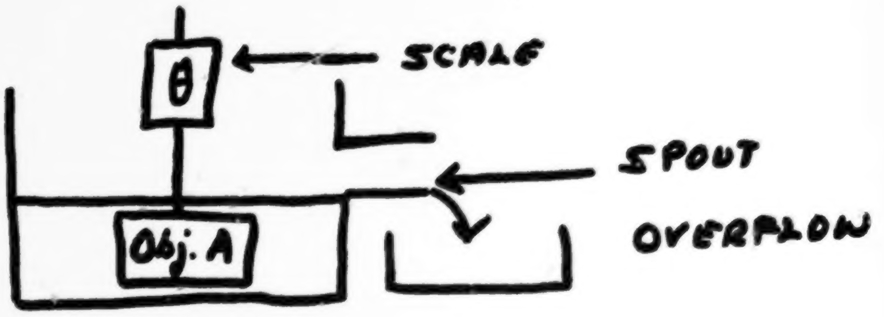
   A. There are liquids in which a rock can displace its own weight.
   B. A rock is always lighter than the liquid it displaces.
   C. There are no liquids in which a rock can displace its own weight.
   D. The rock always displaces an amount of water equal to its own weight.

7. In view of what Archey found out from this experiment, the next step he should take is to

   A. use more blocks of different materials.
   B. determine the weight of the water that overflows when a block sinks.
   C. substitute different liquids for water.
   D. use objects of different shapes.

SET XIV
(Displacement: Submerged Objects)

Archey performed the following experiment. First, he weighed different objects. Then he submerged the objects in an overflow can and weighed both the object and the water which overflowed from the can. He repeated the experiment with several objects and recorded the data shown below.



Object	Weight of objects in air	Weight of objects submerged	Weight of water overflowing
"A"	3 lbs.	2 lbs.	1 lb.
"B"	5 lbs.	3 lbs.	2 lbs.
"C"	10 lbs.	9 lbs.	1 lb.

After studying the data Archey concluded that an object submerged in a liquid is buoyed or pushed up with a force equal to the weight of the liquid it displaced.

1. The word "buoyed" means

   A. displaced.
   B. floated.
   C. pushed up.
   D. submerged.

2. Archey's conclusion was:

   A. An object submerged in a liquid is buoyed up with a force equal to the weight of the liquid displaced.
   B. The amount of liquid displaced equals the weight of the object.
   C. A submerged object weighs the same as an object weighed in air.
   D. The weight of an object in air is less than the weight of a submerged object.

3. Archey concluded that an object submerged in a liquid is buoyed up with a force equal to the weight of the liquid. Another way of stating this is:

   A. The amount of water displaced equals the weight of the object in air plus the weight of the object submerged.
   B. The force of buoyancy is greater than the weight of water displaced.
   C. The weight of the object submerged is greater than the weight of the object in air.
   D. The force of buoyancy equals the weight of the object in air minus the weight of the object submerged.

4. Archey submerged a 6 lb. weight in a liquid and weighed it. He found that it weighed 5 lbs. What was the weight of the water displaced?

   A. 1 lb.
   B. 5 lbs.
   C. 7 lbs.
   D. 11 lbs.

5. A submarine that displaces 1,000,000 tons of sea water when submerged has lost all power and sunk to the bottom. If the submarine weighs 1,100,000 tons in dry dock with its ballasts full of water, how much force will be needed to raise it?

   A. 100,000 tons
   B. 1,000,000 tons
   C. 1,100,000 tons
   D. 2,100,000 tons

6. Archey's conclusion was that an object submerged in a liquid is buoyed, or pushed, up with a force equal to the weight of the liquid. Which of the following is the best statement regarding this conclusion? The statement

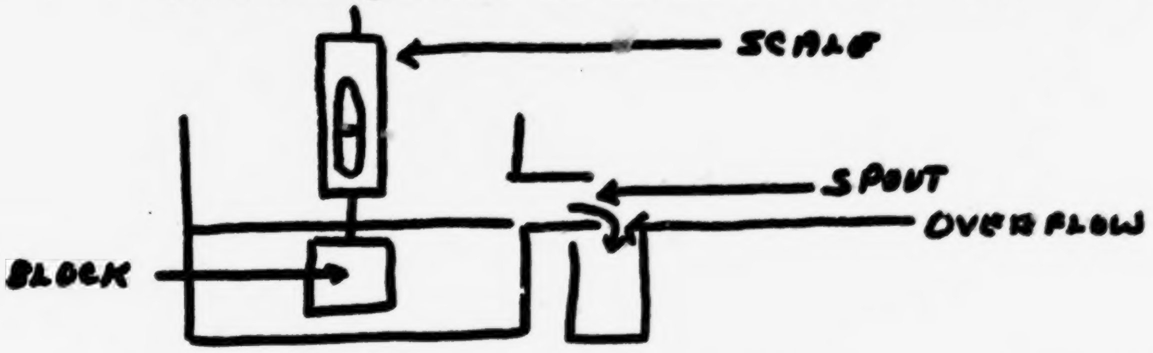
   A. follows from the experiment.
   B. may be wrong since he did not check objects of different densities.
   C. is an example of extending his experimental data too far.
   D. might be justifiable if he had used more objects made in different materials.

7. In the light of Archey's experiment, which of the following is the most logical next step?

   A. Repeat the experiment using heavier objects.
   B. Repeat the experiment using irregular objects.
   C. Repeat the experiment using different liquids.
   D. Use floating objects in the experiment and force them under the water.

SET XV
(Buoyancy)

Archey made three blocks out of different materials which are equal in volume. He then placed one of the blocks into an overflow can filled to the spout with water. (See Figure 1) The block floated and caused the water to overflow. Next he used a spring pressure gauge to immerse, or submerge, the block under the water. He noted that still more ran out of the overflow can. He repeated the experiment with the other two floating blocks and recorded the following data:



Total weight of the water overflowing when the object is submerged		Weight of the blocks	Pressure needed to submerge objects
"A"	8 lbs.	6 lbs.	2 lbs.
"B"	8 lbs.	4 lbs.	4 lbs.
"C"	8 lbs.	2 lbs.	6 lbs.

After studying the data Archey concluded that a floating object will be driven upwards by a force equal to the difference between its weight and the weight of the fluid displaced.

1. Immerse means to

   A. raise above.
   B. lift out.
   C. submerge.
   D. overflow.

2. Archey's conclusion was that:

   A. A floating object will be forced downwards by a force equal to the difference between its weight and the weight of the fluid displaced.

   B. A submerged object will be driven upwards by a force equal to the difference between its weight and the weight of the fluid displaced.
   C. A floating object will be forced downwards by a force when its weight is less than the weight of fluid displaced.
   D. A floating object will be driven upwards by a force equal to the difference between its weight and the weight of the fluid displaced.

3. A floating object will be driven upwards by a force equal to the difference between its weight and the weight of the fluid displaced. Another way of stating this is:

   A. To calculate how much a floating object is forced upwards, find the weight of the fluid displaced minus the weight of the block.
   B. To calculate how much a submerged object is forced downwards, find the weight of the fluid displaced minus the weight of the block.
   C. To calculate how much a floating object is forced downwards, find the weight of the fluid displaced minus the amount of pressure needed to submerge it.
   D. To calculate how much a submerged object is forced upwards, find the sum of the weight of the block and the weight of the fluid displaced.

4. A floating block weighing 10 lbs. is forced beneath the surface of the water in an overflow can, and 18 lbs. of water flow out of the can. What is the upward force acting on the block?

   A. 8 lbs.
   B. 10 lbs.
   C. 20 lbs.
   D. 28 lbs.

5. A toy boat which weighs 10 lbs. when empty is loaded until it has pushed aside 15 lbs. of water. What is the weight of the load placed in the boat?

A. 25 lbs.
B. 15 lbs.
C. 10 lbs.
D. 5 lbs.

6. Bill says, "The deeper an object is submerged the faster it comes to the surface." This statement

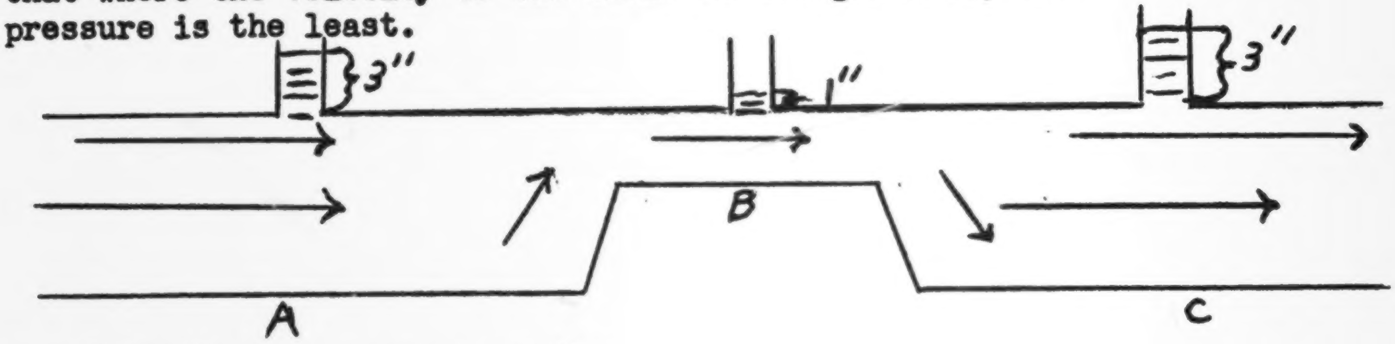
A. can't be true if the experimental results are correct.
B. could be true, but is unrelated to Archey's principle.
C. is false, because if the principle is true the object should rise at a constant speed.
D. is correct and a direct result of the principle.

7. In view of Archey's experiment the next step that should be performed is to

A. measure the object to determine the volume.
B. determine the volume of the liquid overflowing.
C. determine the weight of the liquid overflowing.
D. repeat the experiment using blocks made of different materials.

SET XVI
(Velocity and Pressure)

Dan is experimenting with the pressure of water when it flows through a tube in which the diameter varies. Other experimenters have found that the same amount of water must flow through all sections of a pipe. In Dan's tube, the same amount of water must flow through sections A, B, and C. Since B has the smallest cross-sectional area, the water will have the greatest velocity (or rate of flow) there. He puts open tubes above points A, B, and C and observes how high the water rises in the tubes to determine the water pressure at those points. After observing the results shown in the diagram, he concluded that where the velocity of the water is the greatest, the pressure is the least.



1. Velocity is a measure of the

   A. pressure of the water.
   B. cross-sectional area of the pipe.
   C. rate of flow.
   D. space water occupies.

2. Where the velocity of the water is the greatest,

   A. the diameter of the tube is the greatest.
   B. the water rises the highest.
   C. the pressure is the greatest.
   D. the pressure is the least.

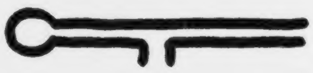
3. Dan stated that where the velocity of the water is the greatest, the pressure is the least. Another way of saying this is:

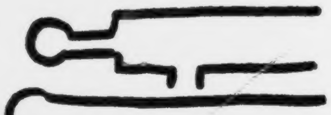
   A. The faster the water flows, the greater the pressure.
   B. The slower the water flows, the greater the pressure.
   C. The greater the area, the greater the velocity.
   D. The smaller the area, the less water will flow through it.

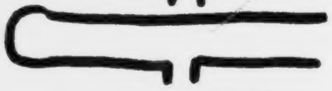
4. If the area at C is changed so that its cross-sectional area is smaller than the area at A but larger than the area at B, then the greatest pressure is at

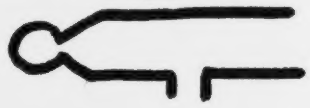
   A. A.
   B. B
   C. C
   D. A and C.

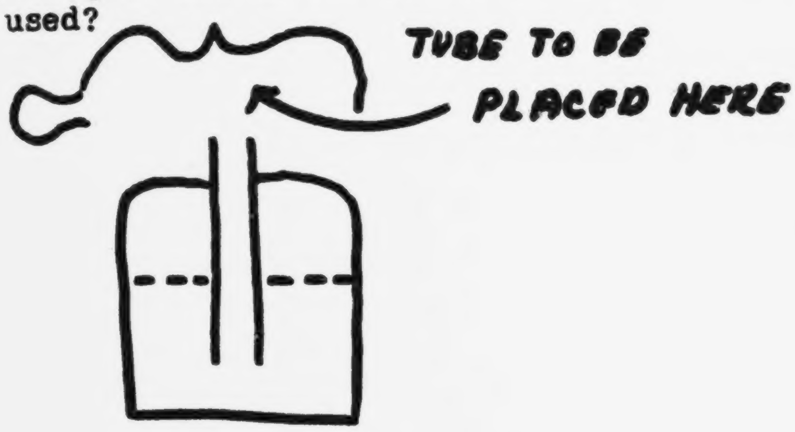
5. To get the greatest amount of liquid out of the atomizer shown, which tube should be used?

A. 

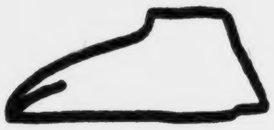
B. 

C. 

D. 



6. Assuming all four of these cars have the same weight and disregarding their centers of gravity, which will be the least stable?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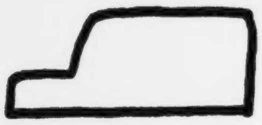
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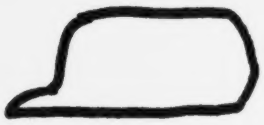
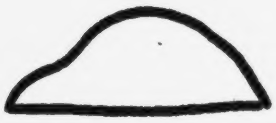

C.


D.

7. The best question to ask after performing the original experiment is:

A. What will be the effect of doubling the pressure at A?
B. Does water escape through the vertical tubes if the pressure is increased?
C. What effect will changing the size of C have?
D. Do gases and liquids behave similarly?

SET XVII
(Gravitational Acceleration)

Bob dropped several balls and recorded the following information:

Time in seconds	Distance ball falls
1	16 feet
2	64 feet
3	144 feet

Bob knew that the acceleration, or change of speed, of an object due to gravity is 32 feet per second squared.

He concluded that the distance an object falls is equal to $\frac{1}{2}$ of the acceleration due to gravity multiplied by the time squared (squared means the number multiplied by itself).

1. Acceleration is

   A. speed.
   B. distance.
   C. change in speed.
   D. time.

2. The distance an object falls is equal to
   A. acceleration times the change in speed.
   B. $\frac{1}{2}$ the acceleration due to gravity multiplied by the time squared.
   C. 32 multiplied by the number of seconds a body falls.
   D. $\frac{1}{2}$ of the acceleration of gravity multiplied by the time.

3. If "s" equals the distance and "t" the time, then s =

   A. $32\ t^2$
   B. $32\ \frac{t}{2}$
   C. $16\ t^2$
   D. $\frac{1}{2}(t)^2$

4. Suppose a ball is dropped. How far will it fall in 4 seconds?

   A. 144 feet
   B. 256 feet
   C. 288 feet
   D. 400 feet

5. A rock is dropped from a cliff that is 1600 feet high. How many seconds will it be before the rock hits the river at the bottom of the cliff?

A. 5 seconds
B. 10 seconds
C. 50 seconds
D. 100 seconds

6. Since Gallileo found that it was very hard to measure very short periods of time for freely falling bodies, he gathered information about acceleration by rolling balls down an inclined plane. From this information he predicted how freely falling bodies would accelerate. He was assuming that

A. air resistance on freely falling bodies is small.
B. objects fall with constant acceleration.
C. data from the inclined plane experiment would be the same as that for free fall.
D. inclined planes are frictionless.
E. inclined planes have nearly the same effect on the object as free falling does.

7. To test whether there is any relationship between the falling, or vertical, motion of an object and the forward, or horizontal motion a man uses cannons set at the edge of a cliff. The best experiment he can do is to:

A. Fire the cannon with varying amounts of force and observe where the balls land.
B. Fire 2 cannons at the same time at different angles and observe when the balls land.
C. Aim a cannon so that it is parallel to the ground, shoot it, and at the same time drop another ball, then observe where the balls land.
D. Do "c" except observe when the two balls land.

SET XVIII
(Elasticity)

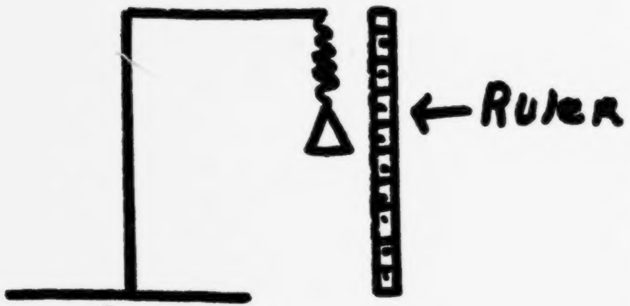


FIGURE 1

Bob had a spring whose elasticity he wanted to test. Elasticity is the property of matter that allows it to return to its original shape after being distorted. He used an apparatus as in Figure 1 where a spring suspends a weight and a ruler is arranged so the position of the weight at the bottom of the spring can be measured. He recorded the following data while performing this experiment:

Force or Weight (grams)	Distance (centimeters)
0.0	0.0
50.0	1.0
100.0	2.0
150.0	3.0
200.0	4.0
250.0	5.0

From this data Bob generalized that the distance an object is stretched is directly proportional (each time the weight increases 50 grams, the distance increases 1 centimeter) to the force exerted on the object or $F = kd$ where F is the weight, d is the distance, and k is a constant number.

1. Elasticity is the property of matter that allows

   A. matter to be pounded into different shapes.
   B. matter to stretch.
   C. the surface of a liquid to contract.
   D. matter to return to its original shape after being distorted.

2. The relationship that Bob found was that the distance an object is stretched

   A. is inversely proportional to the force exerted on the object.
   B. is directly proportional to the force exerted on the object.
   C. is independent of the force exerted on the object.
   D. varies when different forces are exerted on the object.

3. Another way of stating Bob's principle is:

   A. The distance stretched equals the constant value times the force.
   B. The constant value equals the distance stretched times the force.
   C. The force equals the distance stretched times a constant value.

4. If Bob added 300.0 grams to the spring, how far would the spring stretch?

   A. 5.0 centimeters
   B. 6.0 centimeters
   C. 6.5 centimeters
   D. 7.0 centimeters

5. If a diving board is pushed down 4 inches when a 120 pound boy stands on its end, how much will it be pushed down when a 180 pound boy stands on it?

   A. 5 inches
   B. 5½ inches
   C. 6 inches
   D. 6½ inches

6. Bob added two more weights and recorded this data:

Weight (grams)	Distance (centimeters)
350	7.5
400	9.5

During this part of the experiment he noticed that the spring was not as bouncy as before. The discrepancy between the data and all previous data can best be explained by which of the following statements?

A. Too much use caused the spring to sag, throwing off the results.
B. The elastic limit of the spring was too low to permit accurate measurement.
C. After a certain force is applied, the distance is directly proportional to the force.
D. The spring remained permanently distorted since the elastic limit was exceeded.

7. Considering only Bob's experiments, which is not the best question to ask?

A. Does $F = kd$ always hold?
B. Is k the same for all materials?
C. Will a spring made of a less elastic material act differently?
D. Does every spring have an elastic limit?

SET XIX
(Force and Motion)

David wished to investigate the relationship between motion and the strength of a force (a push or pull that produces or retards motion). He decided to roll two balls on a level plastic table to eliminate the effect of friction. He applied equal forces on the balls to set them in motion and then recorded how far each one rolled per second.

Weight of ball		Distance traveled IN EACH SECOND		
	0 sec.	in first sec.	in second sec.	in third sec.
5 ounces	0 inches	10 in	10 in	10 in
10 ounces	0 inches	5 in	5 in	5 in

From this information David concluded that when there is no force exerted on a moving object, the object will move in a straight line at a constant speed.

1. Force is

   A. motion.
   B. a push that produces motion.
   C. a pull that retards motion.
   D. a push or pull that produces or retards motion.

2. David concluded that when there is no force exerted on a moving object, the object will

   A. gradually move slower and slower until it stops.
   B. gradually move faster and faster until it hits something.
   C. move in a straight line at a constant speed.
   D. immediately stop moving.

3. Another way of stating David's conclusion would be to say that:

   A. If NO friction or other force is applied to a moving object, the object will gradually slow down.
   B. If NO friction is applied to a moving object, the object will move at a constant speed in a straight line.
   C. If friction is applied to a moving object, the object will move at a constant speed in a straight line.
   D. If a force other than friction is applied to a moving object, the object will move at a constant speed in a straight line.

4. If a 10 pound ball is rolling on a frictionless surface and it travels 5 feet in the first 5 seconds, how far will the ball roll in the next 10 seconds?

   A. 5 feet
   B. 10 feet
   C. 25 feet
   D. 50 feet

5. David rolls a bowling ball down a lane which is 60 feet long. If the ball moves 6 feet in the first second, how many seconds will it take for the ball to reach the end of the lane?

   A. 5 seconds
   B. 10 seconds
   C. 15 seconds
   D. 20 seconds

6. David repeated his experiment, but this time he continued to apply a constant force to each ball after it started to roll. For each ball he found the following:

		Distance traveled IN EACH SECOND		
Weight of ball	0 sec.	In 1st sec.	In 2nd sec.	In 3rd sec.
5 oz.	0 in.	12 in.	24 in.	36 in.
10 oz.	0 in.	6 in	12 in.	18 in.

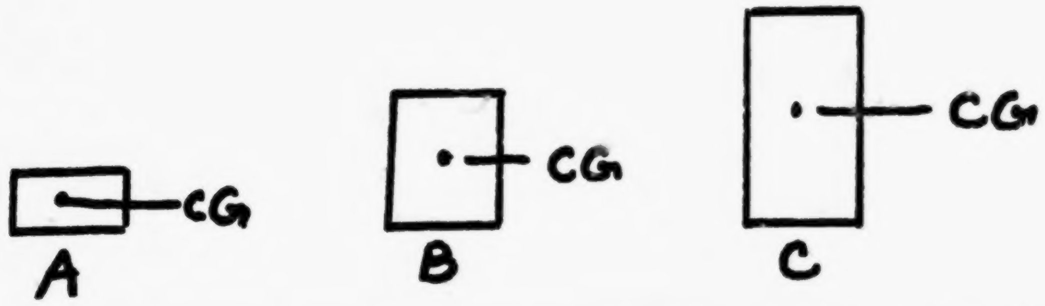
   From this information which of the following would be the BEST conclusion for David to make? If a constant force is applied to a moving ball, the distance the ball moves in each second will

   A. double each second.
   B. increase at a predictable rate.
   C. go 1/3 faster each second.
   D. increase by 12 inches.

7. Which of the following questions should David investigate next?

   A. Does an object move in a similar way when moved over a surface where friction is present?
   B. Does gravity affect the amount of force exerted upon a moving object?
   C. Is there a relationship between the motion of an object and a constant force exerted upon it?
   D. Is there a relationship between the weight of an object and its motion when a constant force is applied to it?

SET XX
(Center of Gravity)



Linda had three different sized blocks that all weighed the same. The center of gravity (labeled C.G.) is the point at which the weight of an object may be considered to be concentrated. Linda measured the amount of force she had to exert at the top edge of each block in order to tip the block.

Block	Distance C.G is from ground	Force needed to tip block over
A	1 inch	25 lbs.
B	2 inches	20 lbs.
C	3 inches	15 lbs.

From this information Linda concluded that the lower the center of gravity, the more stable an object is.

1. The center of gravity is

   A. the point at which the weight of an object may be considered to be concentrated.
   B. above the point where the weight of an object is concentrated.
   C. below the point where the weight of an object is concentrated.
   D. at the center point of the length of an object.

2. According to Linda's conclusion

   A. objects all have their centers of gravity at similar points.
   B. the object with the lowest center of gravity is the least stable.
   C. the lower the center of gravity, the more stable an object is.
   D. the higher the center of gravity, the more stable an object is.

3. Another way of stating Linda's conclusion is:

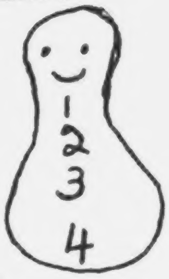
   A. The futher the center of gravity of an object is from the ground, the more force will be necessary to tip it over.
   B. The nearer the center of gravity of an object is to the ground, the less force will be necessary to tip it over.
   C. The closer the center of gravity of an object is to the ground, the more force will be necessary to tip it over.
   D. The amount of force necessary to tip objects over is not related to the position of the center of gravity.

4. Linda had another block which had the same weight as her other blocks. The center of gravity was 4 inches above the ground. How much force will have to be exerted at the top to tip the block over?

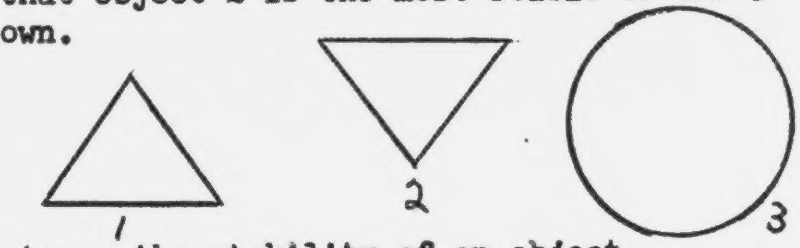
   A. 30 lbs.
   B. 15 lbs.
   C. 10 lbs.
   D. 5 lbs.

5. Linda has a toy clown. She wants to make it as hard as she can for her brother to knock it over. She should place a weight at

   A. 1.
   B. 2.
   C. 3.
   D. 4.



6. John said that object 2 is the most stable of the 3 objects shown.



   If this is true, the stability of an object

   A. depends on the size of the base of the object.
   B. depends on the shape of the object.
   C. depends on the relationship of the size of the base to the center of gravity.
   D. is unrelated to the size of the base.

7. The next experiment Linda should perform is to determine the amount of force necessary to tip over objects with

   A. equal weights and centers of gravity the same distance from the ground.
   B. equal weights but centers of gravity various distances from the ground.
   C. equal weights but different sized bases.
   D. unequal weights and unequal sized bases.

SET XXI
(Gravitational Attraction)

All objects attract each other. The force of attraction between objects is called the gravitational pull. If two small corks are placed 1 foot apart in a large tub of water, they will move together until they touch. However, if the corks are put 2 feet apart in the water, they remain where they are placed.

After observing this experiment, Ron concluded that the gravitational pull between two objects is greater if the objects are closer together.

1. The gravitational pull is the force

   A. of attraction between objects.
   B. which causes objects to float instead of sink.
   C. of magnetic repulsion between like objects.
   D. of the weight of an object.

2. The gravitational pull

   A. is greater if the objects are far apart.
   B. is greater if the objects are close together.
   C. remains constant for any two objects.
   D. depends on the mass of the earth.

3. If the distance between two objects increases, then the

   A. gravitational pull between them will increase.
   B. gravitational pull between them will decrease.
   C. objects will move together.
   D. objects will move together faster.

4. If the objects are placed ½ foot apart,

   A. they would not move.
   B. they would move together until they meet.
   C. they would develop an unlike electrical charge.
   D. one cannot predict what will happen.

5. At a certain time the Earth is farther from Mars than it is from Venus. You would expect from this information that the gravitational pull

   A. would be greatest between Earth and Venus.
   B. would be greatest between Earth and Mars.
   C. would be greatest between Mars and Venus.
   D. depends on the distance they are from the sun.

6. Dick said, "If Ron's principle is true, no matter how far the corks are apart, they should come together." This statement

   A. is correct if the experiment were conducted in a vacuum.
   B. disregards the gravitational pull of other objects on the corks.
   C. is correct if the two corks have equal weights.
   D. is incorrect if they have like charges.

7. The next experiment that Ron should do is to

   A. perform the original experiment in a vacuum.
   B. place 3 or more objects in the tub.
   C. place different objects in the tub at different places.
   D. use objects of different weights.

SET XXII
(Dissolving and Freezing)

Peter decided to find out what happens to the freezing point (the temperature at which a liquid changes to a solid) of water when sugar is added. He used jars containing equal amounts of water. After adding sugar to two jars of water, he placed three jars in a freezer to find the freezing point for each. He found the following:

Jar with	Freezing point
No sugar	32° F
1 ounce of sugar	30° F
2 ounces of sugar	28° F

From this information Peter concluded that the freezing point of a liquid is lowered when a solid is dissolved in it.

1. Freezing point is the temperature at which

    A. a gas becomes a liquid.
    B. a liquid becomes a solid.
    C. ice changes to a vapor.
    D. a liquid becomes a gas.

2. According to Peter's conclusion, the freezing point of a liquid

    A. is not changed when a solid is dissolved in it.
    B. is lowered when a solid is dissolved in it.
    C. is raised when a solid is dissolved in it.
    D. can't be measured when a solid is dissolved in it.

3. Another way of stating Peter's conclusion is:

    A. A liquid will freeze faster if a solid is added to it.
    B. A liquid will freeze more slowly if a solid is added to it.
    C. A liquid freezes at a higher temperature when a solid is dissolved in it.
    D. A liquid freezes at a lower temperature when a solid is dissolved in it.

4. If Peter added 3 ounces of sugar to a jar of water, the freezing point would be

    A. 34°
    B. 32°
    C. 28°
    D. 26°

5. Sally doesn't want the water in her swimming pool to freeze during the winter. She decides to add copper sulfate to the pool. The water in the pool will be least likely to freeze if she adds which amount of copper sulfate?

   A. 1 lb.
   B. 5 lbs.
   C. 10 lbs.
   D. 100 lbs.

6. Ken said, "If Peter's conclusion is correct, then if I put sand in water I will lower the freezing point." His statement assumes that

   A. the water and sand are under pressure.
   B. not all solids dissolve in water.
   C. sand dissolves in water.
   D. the more solid is added, the lower the freezing point.

7. The next experiment Peter should try is to

   A. use different amounts of water and add sugar.
   B. keep the amount of water the same and vary the amounts of different solids dissolved in it.
   C. dissolve different proportions of solute in different amounts of water.
   D. add equal amounts of different solids to equal amounts of water.

SET XXIII
(Electro-Magnetism)

Kathy wrapped wire around an iron rod and connected the wires to a battery to make an electromagnet (a piece of iron which becomes magnetized when electricity passes around it). She tested the strength of the electromagnet by finding how many thumb tacks it could pick up. She found the following:

Number of coils of wire around the rod	Number of tacks picked up
5	10
10	20
20	40
40	80

From this information Kathy decided that the strength of an electromagnet doubles when the number of coils of wire around the core doubles.

1. An electromagnet is

   A. a piece of iron which becomes magnetized when electricity passes around it.
   B. a current passing through a wire coil.
   C. an iron rod with a current passing through it.
   D. any piece of metal which attracts iron.

2. Kathy said that the strength of an electromagnet

   A. decreases when the number of coils of wire around the core doubles.
   B. doubles when the number of coils of wire around the core doubles.
   C. is equal to the number of coils of wire around the core.
   D. is always constant for a given core using the same battery.

3. Another way of stating Kathy's conclusion is by saying that an electromagnet can be made more powerful by

   A. increasing the amount of wire wrapped around the core.
   B. decreasing the amount of wire wrapped around the core.
   C. using a different kind of core.
   D. changing the type and kind of wire.

4. If the iron rod in the original experiment has 80 coils of wire around it, it should pick up

   A. 40 tacks.
   B. 80 tacks.
   C. 160 tacks.
   D. 320 tacks.

5. An old man wished to make his doorbell ring louder. In looking at the bell, he found that by pressing the button at the front door he closed an electrical circuit which allowed an electrical current to pass through a coil of wire around a rod, thus making an electromagnet. A metal clapper was then attracted to the magnet and sounded a gong when it struck. The man said that to make the bell louder, he should

   A. remove the iron core of the electromagnet.
   B. use a larger metal clapper in the bell.
   C. increase the number of turns of wire around the core.
   D. increase the number of turns of wire around the core and decrease the size of the core.

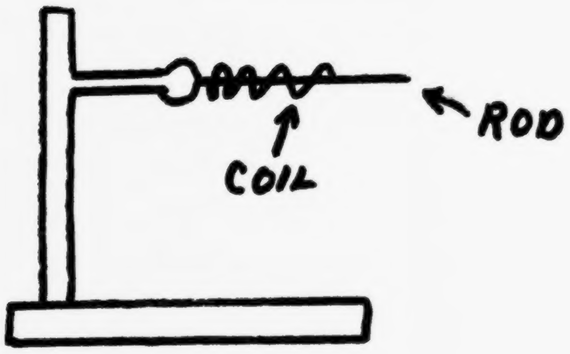
6. John listened to Kathy's conclusion and said, "that means that I can pick up a car with a flashlight battery." John's statement

   A. is correct if what Kathy says is true.
   B. cannot be true if what Kathy says is true.
   C. is correct if what Kathy says is true, but Kathy's statement is wrong.
   D. could be true but is not related to Kathy's conclusion.

7. For Kathy to gain the most useful information, which of the following changes should she make in her experiment?

   A. vary the number of wraps of wire from 1 to 80.
   B. vary the amount of current passed through the wire.
   C. change the kind of objects to be picked up to smaller tacks.
   D. change the direction in which the current flows through the wire.

SET XXIV
(Heat and Expansion)



Joyce placed a copper rod as shown in the drawing above. The rod was heated by placing it in a coil which is electrically heated. She recorded the length of the rod at various temperatures.

Temperature	Length of the Rod	Change in Length
100° F	100.00 inches	
200° F	100.09 inches	.09 inches
300° F	100.18 inches	.09 inches

The rate of change in length of an object due to temperature change is called the coefficient of linear expansion. The length of the copper rod increased .09 inches for every 100° change in temperature or .0009 inches per inch of length per degree change.

Joyce concluded that increasing the temperature of a metal increases its length, and that the coefficient of linear expansion remained the same for a metal.

1. The coefficient of linear expansion is the rate of change

    A. in length of the rod.
    B. in temperature of the rod.
    C. in length due to temperature change.
    D. in metal used.

2. Increasing the temperature of a metal

    A. increases the length.
    B. increases the length by one unit.
    C. increases the coefficient of linear expansion.
    D. will not affect the length at a constant coefficient of expansion.

3. Another way of stating Joyce's principle is:

   A. A long rod will always be hotter than a short rod.
   B. Different metals with constant coefficients of expansion change their length by the same amount.
   C. The length of the rod is independent of the coefficient of linear expansion.
   D. The change in length of a rod is directly proportional to its temperature.

4. If the temperature is 500° F., the length of the rod in the original experiment would be

   A. 99.01 inches long.
   B. 100.00 inches long.
   C. 100.36 inches long.
   D. 136.00 inches long.

5. A surveyor needs an accurate measuring instrument. Below are some coefficients of linear expansion:

Material	Coefficient of Linear Expansion
Invar (an alloy of nickel & iron)	.0000005
Platinum	.000005
Steel	.000007
Tin	.00002

   Which of the above would be the best material to use?

   A. Invar
   B. Platinum
   C. Steel
   D. Tin

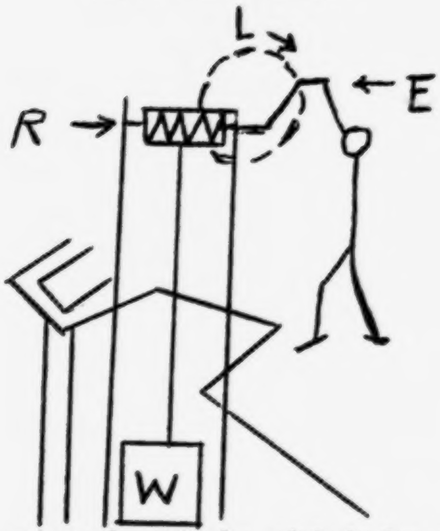
6. After viewing the experiment Joyce stated, "Increasing the temperature of a metal increases its length." Which statement has she accepted as true?

   A. All metals will behave like copper then heated.
   B. Copper has properties UNLIKE other metals.
   C. Other metals can be heated to greater temperatures than copper.
   D. Copper is a good conductor of heat.

7. In view of what Joyce found out from her first experiment the best experiment for her to perform next is to

   A. use different widths of copper rods.
   B. find out if the copper rod will continue to increase in length as the temperature continues to increase.
   C. vary the length of the copper rod and heat it from 100 to 400° F.
   D. cool the copper rod from 400° to 0° and measure the decrease in length.

SET XXV
(The Windlass)



David conducted an experiment in which he used a windlass to lift three different weights. To lift each weight, or resistance force, he used a handle with a different length. He measured the amount of effort necessary on the end of the handle (called the effort force) to lift the different weights, and record the following data:

W - weight or resistance force
R - axles radius
L - length of handle
E - effort force

Length of handle	Effort force	Axles radius	Resistance force
4 inches	2 lbs.	2 inches	4 lbs.
5 inches	4 lbs.	2 inches	10 lbs.
6 inches	3 lbs.	2 inches	9 lbs.

On the basis of this information, David concluded that the amount of effort force (E) multiplied by the length of the handle (L) equals the resistance force (W) multiplied by the axles' radius (R).

1. The resistance force is a measure of

   A. effort used.
   B. weight lifted.
   C. length of the handle.
   D. radius of the axle.

2. According to David's conclusion the

   A. amount of effort force multiplied by the radius of the axle equals the resistance force multiplied by the length of the handle.
   B. amount of the effort force multiplied by the length of the handle is greater than the resistance force multiplied by the radius of the axle.
   C. amount of effort force multiplied by the length of the handle equals the resistance force multiplied by the radius of the axle.
   D. amount of effort force multiplied by the resistance force equals the length of the handle multiplied by the radius of the axle.

3. Another way of stating David's conclusion is

   A. E X R = W X L.
   B. L X R = E X W.
   C. W X R = E X L.
   D. L X W = R X E.

4. If the length of the handle was increased to 7 inches, the effort force is 4 lbs. and the radius of the axle is 2 inches, how heavy a resistance force can be overcome?

   A. 3 lbs.
   B. 9 lbs.
   C. 12 lbs.
   D. 14 lbs.

5. If a farmer uses a windlass to lift a 500 lb. bale of hay, and the handle has a length of 4 feet and axle radius of 1 foot, then how much effort force will be necessary to lift the bale of hay?

   A. 75 lbs.
   B. 125 lbs.
   C. 175 lbs.
   D. 225 lbs.

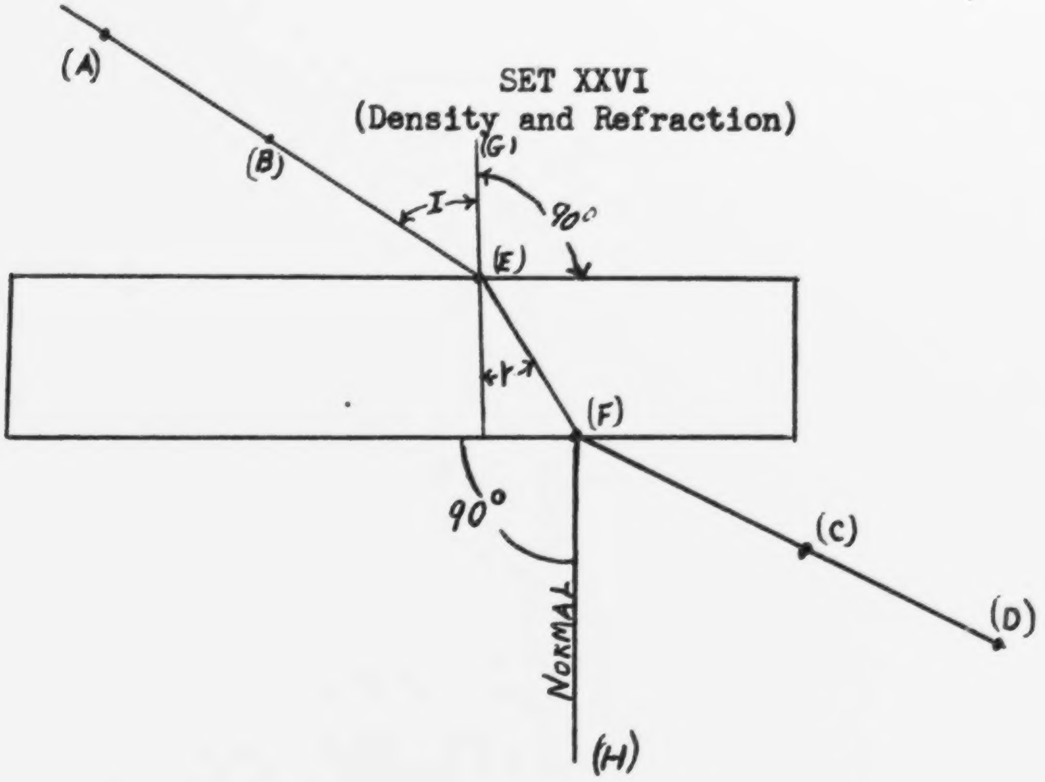
6. David said, "The effort force moves a great distance compared to the short distance moved by the resistance force." This statement is

   A. true- because a small effort force can be used to move a larger resistance force.
   B. true- because the effort force must cover a considerable distance for each revolution of the axle.
   C. false- because the effort force is multiplied by the resistance force.
   D. false- because the rope winds on the axle at the same rate that the weight rises.

7. In view of what David has discovered about the windlass the best question he could ask next is:

   A. Have I created energy?
   B. Does density and pressure affect the resistance force?
   C. How much does friction affect the effort force?
   D. Does the length of the axle affect the effort force?
   E. Does it take as much effort to keep the weight moving as it does to start it moving?

SET XXVI
(Density and Refraction)



Use Figure 1 to help interpret Peter's experiment.

Peter set a small solid piece of glass on a smooth cardboard, and then stuck two straight pins, A and B, into the cardboard so they were in line on one side of the glass. Then he used pins A and B as a sighting line and looked through the glass. As he looked, he stuck two pins, C and D, into the cardboard on the opposite side of the glass so all the pins, A, B, C, and D were in a straight line.

Next Peter drew a line around the glass on the cardboard, and then he removed the glass. He completed his diagram by drawing the following straight lines: (1) a line connecting the positions of pins A and B to the side of the glass at E; (2) a line connecting the positions of pins C and D to the opposite side of the glass at F; (3) a line from E to F; and (4) a line that was perpendicular to the side of the glass at E. Peter labeled this the normal line.

The diagram showed Peter that the four pins were not really placed in a straight line. He measured the angle of incidence, i, or the angle between the normal line and the line formed by pins A and B; and the angle of refraction, r, or the angle between the normal line and the line connecting points E and F.

Peter repeated this procedure four times, but each time he used a substance that was less dense than the glass: a solid piece of clear plastic; gasoline, alcohol, and water--all put in a thin container the same size as the solid piece of glass.

Peter recorded the following:

Substance	Density	Angle of Refraction (Degrees)	Angle of Incidence (Degrees)
Air	0.003	----	--
Gasoline	0.61	26.1	30
Alcohol	0.82	24.2	30
Water	1.00	22.0	30
Plastic	1.22	19.9	30
Glass	1.41	17.9	30

On the basis of this information Peter concluded that light rays are refracted, or bent, toward the normal line when they pass from a less dense to a more dense transparent substance.

1. When light is refracted it

   A. passes through.
   B. stops.
   C. bends.
   D. goes in a straight line.

2. If light passes from a less dense to a more dense substance, it

   A. scatters in all directions.
   B. passes through in a straight line.
   C. bends towards the normal line.
   D. bends away from the normal line.

3. Another way of stating Peter's conclusion is to say that:

   A. light rays are bent when passing from glass to water.
   B. light rays bend downward when they enter a less dense transparent medium.
   C. light rays are bent toward a line constructed perpendicular to its point of contact with a denser transparent medium.
   D. light rays bend downward when they enter a denser transparent medium.

4. If Peter used a substance which had a density of 0.90, the angle of refraction would have been about

   A. 20.4.
   B. 24.8.
   C. 21.0.
   D. 23.1.

5. Peter wants to fill a tank with a transparent liquid so when he shines a light on the surface with angle of incidence of 30 degrees, the light will strike a coin on the bottom of the tank that is 14 degrees from the normal line. To do this Peter should use a transparent liquid that has a density of about

   A. 2.0.
   B. 1.3.
   C. 1.6.
   D. 1.8.

6. After Peter studied the results of his experiments he made another conclusion: The smaller the angle of incidence is, the smaller the angle of refraction toward the perpendicular line. This conclusion is:

   A. related, and supported by the results of his experiments.
   B. not related because the angle of incidence isn't important--only density is.
   C. related, but not supported by the results of his experiments.
   D. not related, because if the light is perpendicular there is no angle of refraction.

7. In view of Peter's experiment the most logical next step would be to ask:

   A. Does the density remain the same when we increase the volume?
   B. What effect would temperature change have on the density?
   C. What is the speed at which light travels through different densities?
   D. Does the wattage of the light have a bearing on the angle of incidence?

SET XXVII
(Temperature and Evaporation)

Alex had heard that all matter is made up of molecules regardless of whether it is in the form of a solid, a liquid or a gas. To find out something more about the molecules Alex performed the following experiment:

First, he filled four pails of the same sizes to the top with water. Then he placed each pail on an electric burner in such a way that the water in the first pail stayed at 110° F, the water in the second pail at 130° F, the water in the third pail stayed at 150° F, while the water in the fourth pail remained at 170° F.

Pail Number	Temperature	Drop in Water Level (Over a 4 Hour Period)
1.	110°	1 inch
2.	130°	2 inches
3.	150°	3 inches
4.	170°	4 inches

Alex studied his data and concluded that adding heat causes the number of molecules of a liquid evaporating, the process of changing from a liquid to a vapor, to increase.

1. Evaporation is the process of changing from a

   A. liquid to a solid.
   B. gas to a liquid.
   C. liquid to a vapor.
   D. solid to a liquid.

2. Alex's conclusion was that adding heat causes the

   A. molecules to move faster in a liquid.
   B. number of molecules of a liquid evaporating to increase.
   C. molecules in a gas to pick up water molecules.
   D. molecules in the liquid to come closer together and take up less space.

3. Another way of stating Alex's conclusion is to say that

   A. vapor pressure is the molecules of vapor above the liquid.
   B. adding heat changes molecules.
   C. increasing the temperature of a liquid increases the rate at which it changes into a gas.
   D. adding heat forces the cooler molecules to the surface where they change into a vapor.

4. In the experiment, how many inches of water would evaporate in a 4 hour period if the water is heated to 210° F?

   A. 6 inches
   B. 8 inches
   C. 5 inches
   D. 7 inches

5. A tobacco farmer is instructed to evaporate 6 inches of water steadily over a 24 hour period in his tobacco shed. He should keep the water at a temperature of

   A. 100°
   B. 110°
   C. 120°
   D. 130°

6. Bill said that Alex's conclusion does not follow from the experiment. Bill is:

   A. right; from his experiment Alex cannot conclude that liquids evaporate faster when more heat is applied.
   B. wrong; Alex's conclusion is right.
   C. right; from his experiment Alex only should conclude that heat makes molecules move faster.
   D. wrong; from his experiment Alex did prove that all matter is made up of molecules.

7. The next experiment Alex should perform is to:

   A. mix other liquids with the water and repeat the experiments.
   B. reverse the experiment by cooling to different degrees.
   C. repeat the experiment using different temperatures.
   D. repeat the experiment using liquids of different densities.

SET XXVIII
(Dominant and Recessive Traits)

Gregory found some tall bean, pea and wheat plants which when he crossed, the pea with the pea, the bean with the bean, and the wheat with the wheat, always produced other tall plants. Next he found some short pea, bean and wheat plants, which when crossed with each other always produced short (bean, pea and wheat) plants. Plants which produce offspring that always have the same particular characteristics as the parents are called homogeneous. The first generation of plants above are all homogeneous.

Gregory then crossed each tall plant with a short plant. He observed the offspring (second generation) and recorded the following data:

200 tall bean plants
400 tall wheat plants
800 tall pea plants

After observing the second generation, Gregory concluded that the trait for tall masks or is dominant over the recessive trait for short.

1. Homogeneous plants are ones tha have

   A. hidden traits of the parents.
   B. second generation characteristics.
   C. same particular characteristics as the parents.
   D. different characteristics of the parents.

2. Gregory's conclusion was that the trait for tall masks or

   A. is equal to a recessive trait for short.
   B. destroys a recessive trait for short.
   C. is masked by a recessive trait for short.
   D. is dominant over the recessive trait for short.

3. Another way of stating Gregory's conclusion is that if all the offspring from first generation plants have the characteristic of one parent and not the other parent then

   A. both parents have a dominant trait.
   B. both parents have a dominant trait that masks a recessive trait.
   C. both parents have a recessive trait.
   D. one parent has a dominant trait that masks a recessive trait in the other parent.

4. Gregory crossed 400 tall corn plant with 400 short corn plants. Each crossing produced one corn plant. Tall corn had the dominant characteristics and short corn had the recessive characteristics. Gregory's experiment will produce

   A. 400 short corn plants.
   B. 300 tall corn plants and 100 short.
   C. 400 tall corn plants.
   D. 200 tall corn plants and 200 short corn plants.

5. A biologist crossed 25 white rats with 25 white rats, 50 black rats with 50 white rats, 200 black rats with 200 black rats. If black is dominant and white is recessive, and each crossing produced only one offspring, the offspring would be:

   A. 50 white rats and 300 black rats.
   B. 25 white rats and 300 black rats.
   C. 25 white rats and 250 black rats.
   D. 50 white rats and 500 black rats.

6. In light of the experiment, Gregory knew that the tall plants had a dominant trait which masked the recessive trait of the short plant. So he could be sure that as long as he crossed plants with both a dominant trait and a recessive trait all the offspring would have the dominant characteristic.

   A. true- because the dominant trait always masks the recessive trait.
   B. false- the experiment hadn't been carried out far enough to draw this conclusion.
   C. true- because dominant + dominant and dominant + recessive always produces dominant characteristics.
   D. false- because a recessive trait may become dominant.

7. In view of Gregory's experiment the next logical experiment to perform would be to

   A. cross recessive with a second generation.
   B. cross second generation with a second generation.
   C. cross dominant with a second generation.
   D. all of the above are logical next experiments to perform.

SET XXIX

(Mendel's 3 to 1 Ratio)

Gregory crossed 200 second generation tall bean plants with each other, 400 second generation tall wheat plants with each other and 800 second generation tall pea plants with each other. he observed the offspring (third generation) and recorded the following data:

Tall bean plants	150	Short bean plants	50
Tall wheat plants	300	Short wheat plants	100
Tall pea plants	600	Short pea plants	200

In a previous experiment Gregory had concluded, that first generation plants were "homogeneous" because they produced offspring with the same characteristics. From the data he concluded that there were hidden traits which can cause the tall plants to reproduce short plants. Plants of this type--second generation plants--he called "heterogeneous". Heterogeneous means that hidden traits are present in the offspring. Finally, he concluded that if heterogeneous tall plants are crossed, the offspring will be produced in a ratio of 3 tall to 1 short.

1. Heterogeneous means an offspring has

   A. recessive traits present.
   B. more dominant than recessive traits present.
   C. hidden traits present.
   D. dominant traits present.

2. Gregory concluded that

   A. the prediction of the offspring from crossing heterogeneous tall palnts is not possible.
   B. the recessive traits in tall plants change to a dominant trait to produce a short plant.
   C. if heterogeneous tall plants are crossed the offspring will be produced in a ratio of 3 tall to one short plant.
   D. if heterogeneous tall plants are crossed the dominant trait causes all the plants to be tall.

3. Another way of stating Gregory's conclusion is, if one offspring out of four is produced with a recessive characteristic from parents displaying a dominant characteristic. The parents must be:

   A. homogeneous and heterogeneous.
   B. homogeneous and homogeneous.
   C. heterogeneous and heterogeneous.
   D. Both A and C.

4. If Gregory crossed heterogeneous tall corn plants with each other the proportion of offspring he should expect is

   A. 600 tall and 600 short corn plants.
   B. 900 short and 300 tall corn plants.
   C. 900 tall and 300 short corn plants.
   D. 1200 tall corn plants and no short.

5. If two heterogeneous fruit flies are crossed (the flies have characteristics for both straight and curved wings), and straight wings are dominant, the characteristics of the 2400 offspring would most likely be

   A. 600 with curved and 1800 with straight wings.
   B. 1200 with curved and 1200 with straight wings.
   C. 1800 with curved and 600 with straight wings.
   D. 2400 with straight wings.

6. If two hetergeneous tall plants are crossed, which of the following arrangements of traits can be used to explain the proportion of tall plants to short. "T" stands for dominant tall, "t" stands for recessive short.

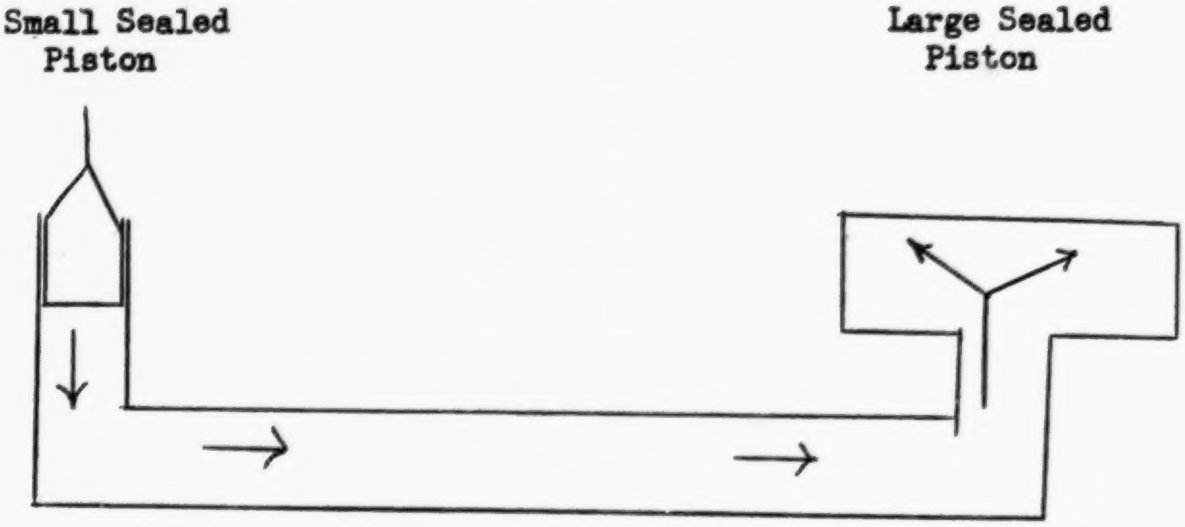
   A. Tt Tt Tt Tt
   B. TT Tt Tt tt
   C. TT tt TT tt
   D. TT tt tt tt

7. In light of the experiment Gregory has performed the best question to ask next is

   A. What happens when plants with recessive traits for the same characteristics are crossed?
   B. If there are two traits for the same characteristic, can they both be recessive?
   C. What happens when two heterogeneous plants are crossed?
   D. What happens when a plant with recessive traits for a particular characteristic is crossed with a plant with dominant traits for the same characteristic?

SET XXX
(Hydraulic Pressure)

Jim used a hydraulic press and performed the following experiment. He recorded the results as shown below:



Pressure applied at small piston	Area of the small piston	Pressure transferred to the large piston	Area of the large piston
p.	a.	P.	A.
10 lbs.	1 sq. inch	50 lbs.	5 sq. inches
20 lbs.	2 sq. inches	100 lbs.	10 sq. inches
30 lbs.	3 sq. inches	150 lbs.	15 sq. inches

After observing the data Jim concluded that the pressure (P), or force distributed through the liquid, that is transferred to the large piston is equal to the pressure (p) applied at the small piston times the number of times the area of the large piston (A) is greater than the area of the small piston (a).

1. In the experiment pressure is defined as:

   A. force exerted at the small piston.
   B. force distributed through the liquid.
   C. transferrable without loss in an enclosed system.
   D. force received at the large piston.

2. Jim's conclusion was that the

   A. pressure tansferred to the large piston is equal to the differences of the distance times the pressure applied at the small piston.
   B. pressure exerted at the small piston is equal to the differences of the area of the pistons times the pressure transferred to the large piston.
   C. pressure transferred to the large piston is equal to the pressure applied at the small piston times the number of times the area of the large piston is greater than the area of the small piston.
   D. distance the larger piston moves is equal to the number of times the area of the small piston can be divided into the area of the large piston times the pressure at the small piston.

3. Another way of stating Jim's conclusion is

   A. $P = A \times a \times p$.

   B. $P = p \times \frac{A}{a}$

   C. $p = P \times A \times a$.

   D. $p = P \times \frac{A}{a}$

4. If Jim wanted to transfer 200 lbs. of pressure to the large piston, he must apply a pressure of ________lbs. at the small piston.

   A. 50 lbs.
   B. 70 lbs.
   C. 60 lbs.
   D. 40 lbs.

5. A mechanic wanted to raise a car that was placed on top of a large piston. The car weighed 2000 lbs. and he had a pressure of 100 pounds to apply to the small piston. If the area of the small piston is 20 square inches what must be the area of the large piston in order to just raise the car?

   A. 50 square inches
   B. 400 square inches
   C. 200 square inches
   D. 2000 square inches

6. Jim said that if the bottom of the large piston were curved then it would lift more weight for each pound of pressure at the small piston. This statement

   A. means the same thing as his first conclusion.
   B. cannot be true if his first conclusion was true.
   C. is true and consistent with his first conclusion.
   D. assumes that a liquid can be compressed.

7. In view of the experiment that Jim had just performed, the next best experiment for him to perform would be to

   A. change to another type of fluid.
   B. increase the pressure at the small piston.
   C. substitute air for fluid.
   D. change the areas of the small and large pistons.

SET XXXI
(Reflection of Colored Light)

A man placed a red ball, a green ball, and a blue ball under a small beam of red light in a dark room. The red ball looked red, but the green ball and the blue ball looked black. He then changed the red light to blue. When the blue ball was placed under the blue light, it looked blue. However, when he placed a yellow ball and a violet ball under the blue light, they looked black.

Next, he placed a light meter beside each ball, but out of the direct beam of light. The light meter showed light to be present when the red ball was under the red light, and when the blue ball was under the blue light, but not in any of the other cases.

From the two experiments he concluded that objects looked black if they absorb or soak up light; otherwise they look the color of the light that is reflected.

1. The word absorb means to

   A. bend back.
   B. scatter.
   C. separate.
   D. soak up.

2. Objects look black if they

   A. reflect or bend back light.
   B. diffuse or diverge light.
   C. absorb or soak up light.
   D. scatter or spread light.

3. In view of the above experiment it seems that it can be said that objects placed under a colored light will look

   A. the same color as the light.
   B. the color formed by the mixing of the color from the light and the color from the object.
   C. their normal color only if the light is the same color as the object. Otherwise the object will look black.
   D. black.

4. If a violet ball is placed under a green light, it will appear

   A. black.
   B. green.
   C. red.
   D. white.

5. A woman who is preparing a halloween party wants her many colored room to look orange and black. She has many orange things in her room. She can make her room look orange and black by using

   A. white light.
   B. yellow and red lights.
   C. orange light.
   D. red light.

6. The experimenter who had performed the experiment with the balls and the colored light then said, "If I place a red ball under a yellow light, it will look black." Which of the following statements has the man accepted as correct?

   A. Red objects will NOT absorb yellow light.
   B. Red objects will absorb yellow light.
   C. Yellow light reflects from red objects.
   D. None of the above statements was accepted.

7. If you could ask the experimenter one question about the experiment which could be answered by a "yes" or "no," which of the following questions would you ask in order to get the most information regarding the reflection and absorption of light by colored objects?

   A. Would a green ball look black under a yellow light?
   B. If a ball is a different color from the light, does it always look black?
   C. Would a violet ball under a violet light look violet?
   D. Would a red ball look black under an orange light?

8. A man whose suit is really green committed a murder in the Spectrum Club (a night club which has seven rooms each containing a different colored light). The murder was committed in the yellow room. The murderer then ran through the violet, green, red, orange, and blue rooms. The witnesses who actually saw the murderer running through the five rooms responded as follows:

Witness "A" in the violet room said the man had on a red suit.
Witness "B" in the green room said the man had on a green suit.
Witness "C" in the red room said the man had on a blue suit.
Witness "D" in the orange room said the man had on a black suit.
Witness "E" in the blue room said the man had on a white suit.

Inspector Jones, not knowing that the murderer's suit was really green, looked at the data about the way the colored balls looked under two different colored lights and decided that witness "D" was telling the truth and arrested the only man in the club wearing a black suit.

THE WITNESSES MAKING TRUE STATEMENTS ARE TELLING THE TRUTH.

Considering the information that the inspector had, he was

A. wrong when he believed witness "D" and wrong when he arrested the man in the black suit.
B. right when he believed witness "D" and right when he arrested the man in the black suit.
C. wrong when he believed witness "D" but right when he arrested the man in the black suit.
D. right when he said witness "D" was telling the truth, but wrong when he arrested the man in the black suit.